Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PHASE II REPORT ON DEVELOPMENT AND EVALUATION OF CEMENT/FLY ASH - BASED SEALANTS FOR CAPPING PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

PREPARED FOR
SCIENCE & SERVICES DIRECTORATE
SUPPLY AND SERVICES CANADA
HULL, QUEBEC

CONTRACT NO. 23440-8-9164/01-SQ
SSC FILE NO. 015SQ.23440-8-9164

BY
HARDY BBT LIMITED
BURNABY, B.C.

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MICROMEDIA

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1.0 INTRODUCTION

Hardy BBT Limited are pleased to submit the Phase II Report on Development and Evaluation of Cement/Fly Ash - Based sealants for Capping Pyritic Slate outcrops at Halifax Airport. The terms of reference of this study are detailed in the Supply and Service Contract No. 23440-8-9164/01-SQ. This report presents the results of the Phase II study up to and including the 28 day test data.

1.1 BACKGROUND

This study evolved from the need to provide a mitigative solution to the problem of acid leachates from exposed pyritic slates at the Halifax airport. This pyritic slate is susceptible to breakdown from exposure to the atmosphere and penetrating rain and surface waters. Bacterial attack of the slate and other chemical processes have led to the generation of leachates which are highly acidic and carry with them heavy metals and other potentially toxic elements. The release of these contaminants into the local ground water system has serious environmental implications.

One of the possible control measures available is the reduction of the penetration of surface water into the slate outcrop. This study focuses on the material properties of one of the possible capping systems - high volume fly ash/portland cement shotcrete with integral high volume fibrillated polypropylene fibre reinforcement (PFRS). The Phase I portion of the study evaluated a broad range of laboratory trial mix designs from which the most promising mixes were identified for the full scale shotcrete test program in Phase II. Some of the key items that will be commented on in this Phase II Report are as follows:

- Low water permeability - effectiveness of the capping material is evaluated based on the water permeability of the shotcrete matrix, as well as its resistance to shrinkage cracking as evaluated in restrained shrinkage tests.

- Long term durability - Resistance of the capping material to cycles of freezing and thawing is being tested directly by laboratory testing to ASTM C666 and field exposure, while qualitative assessments are made based on overall strength, and ductility. CANMET will be further assessing the quality of the shotcrete in assessment of the characteristics of the air void system and water permeability.

- Ductility - the ability of the capping material to resist tearing, cracking, or damage from stresses and deformations typical in this application is evaluated based on flexural strength and toughness index parameters.

- Chemical resistance to seeping leachates - no specific testing has been conducted but qualitative statements are presented based on boiled absorption and permeable void tests.

- Commercial viability - comments are made regarding the ease of producing and installing the capping material.

1.2 SCOPE OF WORK

The scope of work conducted in the Phase II Study was set out in Appendix A of the Contract Document and in subsequent communications with CANMET.

Based on the results of Phase I and on complementary investigations carried out at CANMET, six mixes were selected for full scale shotcreting and fabrication of shotcrete test panels. The principle mix variables are:

- two cementitious contents
- three addition rates of polypropylene fibres: 0%, 3%, and 6%

Two large test panel assemblages were fabricated and shotcreted for restrained shrinkage testing by Hardy BBT. One test panel has a fully bonded bedding while the other has unbonded bedding to represent the range of bedding conditions found at the Halifax airport. The panels are presently being subjected to exposure to normal outdoor

Vancouver weather. The specimens are to be monitored periodically for crack size, pattern and spacing, and general weathering performance.

Smaller shotcrete test panels were fabricated from which specimens were procured for determining the following properties of the hardened shotcrete:

- Compressive strength testing on 75 mm diameter cores at ages of 7, 28 and 56 days. In addition shotcrete cylinders, were made by shooting into 150 x 300 mm cylinder moulds. These cylinders are being tested at the same ages as the 75 mm cores for direct comparison of the two methods of fabricating compressive strength specimens.

- Prisms, (75 x 75 x 355 mm), for determination of flexural strength, and ASTM C1018 Toughness Index Parameters, (I_5, I_{10}, and I_{20}), at an age of 28 days.

- 75 x 90 x 405 mm prisms were saw cut for testing in accordance with ASTM C666 Resistance of Concrete to Rapid Freezing and Thawing (Procedure A). Specimens were placed in the Logan freeze/thaw test unit at an age of 28 days.

- 75 mm cubes were tested according to ASTM C642 Specific Gravity, Absorption and Voids in Hardened Concrete.

- 150 mm diameter cores have been shipped to CANMET for testing for water permeability and air void parameters of the hardened shotcrete.

2.0 TEST PROGRAM AND RESULTS

2.1 SHOTCRETE MATERIALS

2.1.1 Portland Cement

The portland cement used in this study was supplied by St. Lawrence Cement from Beauport, Quebec and conforms to the requirements of CAN/CSA-A5-M88 for a Type 10

portland cement. Typical physical and chemical properties of the cement are given in Table 1 in Appendix A.

2.1.2 Fly Ash

A low calcium fly ash conforming to CAN/CSA-A23.5-M86 Type F was used in this study. The fly ash is a waste product from a thermal generation plant at Lingan, Nova Scotia and is marketed for use in concrete by Nova Scotia Sand & Gravel. Typical physical and chemical properties of the fly ash are given in Table 2 in Appendix A.

2.1.3 Aggregates

The aggregates used in this study were supplied by Target Products Limited of Burnaby, British Columbia. These aggregates are routinely used in shotcrete production in Western Canada and have proven acceptable performance in concrete and shotcrete in exterior exposure conditions. Gradation analyses of the 10 mm coarse aggregate fraction, and shotcrete sand are given in the appended Technical Reports #B1 and #B2 respectively in Appendix B. The aggregate was combined so that the coarse aggregate was 30 % by mass of the total combined aggregate. The combined aggregate gradation is shown in Technical report #B3 in Appendix B. Note that the combined aggregate falls just outside the fine side of the ACI 506R-85, Table 2.1, Gradation No. 2 envelope on the 1.25 mm and 630 mm sieves, but this is undesirable for high volume polypropylene fibre reinforced shotcretes.

2.1.4 Chemical Admixtures

The superplasticizer used was "DURASAR" supplied by Handy Chemicals Limited of La Prairie, Quebec. It is a naphthalene sulphonate calcium salt. Product literature and typical physical property data are given in Appendix D. It is understood that "DURASAR" conforms to the requirements of CAN3-A266.6-M85 Superplasticizer Admixtures for Concrete. No additional water reducing admixtures were added to the mixes.

2.1.5 Polypropylene Fibre

The fibre used in this study was 38 mm long "FORTA CR" twisted, fibrillated, polypropylene fire, supplied by Elsro Construction Products, St. Albert, Alberta. The fibre is manufactured by the Forta Corporation of Grove City, Pennsylvania, U.S.A. Product literature is included in Appendix D.

2.2 SHOTCRETE MIX DESIGNS

A summary of the as batched mix proportions, used in the test program, is given in Technical Report #A1 in Appendix A. Detailed yield analyses of the mixes based on as-batched quantities are given in Technical Reports #B4 to #B9 in Appendix B.

Mixes U, V, and W have a total cementitious content in the range of 418 to 430 kg/m^3 of which 63% is fly ash and mixes X, Y and Z have a total cementitious content in the range of 471 to 487 kg/m3 of which 64% is fly ash. The Phase I report recommended a minimum cement content of 400 kg/m^3. Water to cementitious materials ratios ranged from 0.29 to 0.36 with one outlier at 0.25 (Mix U).

The sand content is 70% of the total aggregate mass, which is typical for wet mix polypropylene fibre reinforced shotcrete.

2.3 BATCHING, MIXING, SUPPLY, AND APPLICATION

The fly ash, cement and dry aggregates were weigh batched and prebagged in bulk bin bags by Target Products. Mixing water was weighed by placing a "45 gallon drum" on a 225 kg scale. The estimated water demand was corrected for absorption of the as-batched aggregate masses and approximately 2/3 this water was pumped into a transit mix truck followed by the dry materials which were discharged into the mixer with a high-lift forklift. Most of the remaining estimated water requirement was added followed by addition of the DURASAR superplasticizer and the air entraining admixture. The mixture was allowed to mix thoroughly by rotating the transit mixer drum at full mixing speed. Slump was measured and water was added until the required initial slump was achieved. Air content was measured and adjusted upwards if necessary. The required amount of fibre was added and slump and air were measured again. Additional water was added as necessary to

produce the required workability for pumping and shooting. All water additions were recorded.

Mix U, a plain control mix without any fibre addition, was the first mix batched. DURASAR superplasticizer was added to this batch at a high addition rate of 9.5 l/m^3. This mixture had a water demand of only 108 l/m^3 and enabled the assessment of "extreme" water reduction on the pumpability and shootability of a plain shotcrete. While this shotcrete was at flowing consistency (220 mm slump), it was very sticky and cohesive. Pump pressures were excessive and the mixture proved very difficult to shoot through a 50 mm I.D. hose. By changing to a 63 mm I.D. hose, it was possible to adequately shoot the required test panels. The mixture was, however, judged to be "water-starved" and not suitable for use with high volume polypropylene fibre additions. Consequently it was decided to use lower superplasticizer addition rates in all the remaining mixes.

The remaining mixes, V through Z, had DURASAR superplasticizer added at addition rates varying between 4.2 and 5.2 l/m^3. (see Technical Report A1 in Appendix A). The water demand for these mixtures varied between 142 and 158 l/m^3 and the water/cementitious ratio between 0.29 and 0.36. These mixtures were judged to have suitable plastic properties for pumping and shooting.

All the mixtures were shot through the 63 mm I.D. flexible hose. Prior to shooting the mix the lines were cleared of the previous mix until a steady stream of the new mix was obtained. Restrained shrinkage panels were shot first followed by the smaller test panels and the moulded shotcrete test cylinders.

2.4 PLASTIC SHOTCRETE PROPERTIES

A summary of the plastic shotcrete properties is given in Technical Report A2 in Appendix A. Slump and air content were measured before and after the addition of fibres. Air content of the in place shotcrete was measured by directing the stream of shotcrete from the nozzle into the air meter base.

The following are comments with respect to the pumping and shooting characteristics of the different mixtures:

As previously mentioned, Mix U appeared "water starved" and was excessively cohesive and sticky, and difficult to shoot and finish in spite of being at a flowing consistency (220 mm slump). Mixtures V, W, X, Y, and Z all had suitable pumping and shooting characteristics. There was, however, a slight tendency to segregation in the high polypropylene fibre shotcrete mixtures W and Z with some of the coarser aggregate particles being "thrown-out" on the surface of the restrained shrinkage test panels. This, together with more fibres at the surface of these mixtures, made finishing with a bull float more difficult. This was, however, not judged to be a major concern.

All the mixtures were batched with air contents in the range of 8.8 to 12.6 percent before fibre addition. (See Technical Report A2 in Appendix A). The air content of the mixes "as shot" into an air pressure meter base varied between 3.6 and 5.2 percent. It is apparent that a substantial amount of air was lost in the pumping and shooting operation. The air void parameter testing to be conducted by CANMET should provide information concerning the "quality" of the in-place air content ie. are the spacing factor and specific surface adequate for freeze/thaw durability considerations.

2.5 COMPRESSIVE STRENGTH

Standard test panels were produced by shooting into wooden forms. These wooden forms were 600 x 600 x 125 mm and had 45° sloped sides. The panels were covered with polyethylene and left in the cool outdoor environment (3 to 10°C) for the first 6 days of curing in order that they would develop sufficient strength to withstand damage during transport to the laboratory. Following that, panels were moist cured at 23°C in a fog room until the time of testing.

Cores 75 mm diameter x 100 mm long were diamond drilled at age 6 days for 7 day compressive strength specimens and at 24 days for 28 day compressive strength specimens. The specimens (two per mix) were trimmed, capped and tested to CSA A23.2-14C procedures. A summary of the average compressive strength of the two cores at 7 and 28 days is shown in Technical Reports #A3 and #A4 in Appendix A.

There are a complex set of variables influencing compressive strength. These include cementitious content, cement/fly ash ratio, water demand (and hence water/cementitious ratio), air content and polypropylene fibre content. Overall, however, the strongest correlation exists between compressive strength and water/cementitious ratio, with the lower water/cementitious ratio mixes displaying the highest compressive strengths. This is well illustrated in Figure 1 in Appendix A.

Also included in Technical Reports #A3 and #A4 are the 7 and 28 day compressive strength results from the 150 x 300 mm moulded shotcrete cylinders. The results show a good correlation between the strength of cored cylinders and moulded shotcrete cylinders, see Figure 2 and Figure 3. The moulded shotcrete cylinders tended to have slightly lower compressive strengths than the shotcrete cylinders at 28 days, but this trend was not obvious at 7 days. The moulded shotcrete cylinders also showed good repeatability between replicate specimens. However, this was only after approximately 10% of the specimens were rejected because of large voids. Such cylinders were easily identified and were not tested. It is believed that these voids resulted from slight deviations from vertical of the angle of the shotcrete nozzle relative to the cylinder moulds at the time of shooting.

2.6 FLEXURAL STRENGTH AND TOUGHNESS INDEX

Prisms, 75 x 75 x 355 mm, were saw cut for determination of flexural strength in accordance with CSA A23.2-8C, and ASTM C1018 I_5, I_{10}, and I_{20} toughness index parameters after 6 days of field curing followed by 22 days of moist curing at 23 °C. The tests were conducted on a 100 kN servo controlled MTS testing machine. Deflection was measured with a pair of averaging LVDT's. The test results are given in Technical Reports #A3 and #A4 in Appendix A. Load verses deflection data was recorded on a strip chart recorder and the plots are included in Appendix C.

Toughness indexes (I_5, I_{10}, and I_{20}) and residual strengths were calculated based on the output of the load verses deflection data in accordance with ASTM C1018. A common toughness index specification for fibre reinforced shotcretes used in tunnelling, mining, slope stabilization and remedial works is:

$$I_5 \geq 3.5$$
$$I_{10} \geq 5.0$$

Mix Z, containing 6.5 % fibres and 470 kg/m^3 cementitious was the only mix to meet both these requirements. Mix V failed to meet either of these criteria. Mixes Y and W met the above I_{10} limits and nearly met the I_5 limits.

2.7 BOILED ABSORPTION AND PERMEABLE VOIDS

The boiled absorption, volume of permeable voids and bulk relative density of the 6 shotcrete mixes was determined according to the ASTM C642 test procedure. Three 75 mm cubes were cut from the ends of the flexure specimens after 28 day tests were complete and were returned to the fog room until testing at an age of 35 days. Results of the testing are shown in Technical Reports #A3 and #A4 in Appendix A. Results of the tests are consistent with expected behaviour and in all cases indicate dense, well consolidated mixtures. Using rating criteria commonly used in the shotcrete industry in Canada, Mixes U, X, and Y would be considered to be of "excellent" quality and Mixes V, W, and Z, of "good" quality. In ranking the performance of the different mixtures there is good correlation between water/cementitious ratio, compressive strength and values for boiled absorption and volume of permeable voids. This is well illustrated in Figure 1 and Figure 4 in Appendix A.

2.8 AIR VOID PARAMETERS

Cores, 150 mm in diameter, for testing of air void parameters were diamond drilled from the small shotcrete test panels at an age of 24 days and sent to CANMET's Ottawa laboratory for testing. Tests will be conducted to determine spacing factor, hardened air content and specific surface in accordance with ASTM C457 Modified Point Count Method.

2.9 FREEZING AND THAWING DURABILITY

The shotcrete test panels were cured in the field for 6 days and then moist cured in the fog room for a further 16 days. At 23 days after shooting, three prism samples, 75 x 90

x 405 mm were saw cut from the small shotcrete test panel. These prisms were cured in water at 23°C until freeze/thaw testing commenced at 28 days. Freeze/thaw testing is being conducted to ASTM C666 (Procedure A) in a Logan Freeze/thaw test unit to 300 cycles.

The testing will include measurement of fundamental transverse frequency and mass change. Results of the testing will be reported when complete.

2.10 RESTRAINED SHRINKAGE TEST

Two large test panel assemblies were constructed for restrained shrinkage testing, see Figure 5. Shotcrete was applied to a depth of 40 mm over a bedding of Halifax Airport shale in the 1.0 x 3.0 metre steel forms. Two panels were prepared for each of the six mixes. The first panel represents an unbonded situation and has a bedding of small fragments of shale (< 20 mm), compacted with a plate tamper and screeded smooth. The second panel has a bedding of larger slate pieces set firmly into a cement mortar base (approximately 70% of the surface is exposed slate) and represents a fully bonded situation. It is thought that this will cover the extremes of bedding conditions prevalent at the Halifax airport. Each panel is restrained from movement at the long end by a reinforcing steel grid, dowelled into the bulkhead and free to move along the other two side walls, resulting in unidirectional shrinkage stresses.

The panels were protected from the rain for the first 7 days after shooting, by a tented tarpaulin structure, but otherwise have been continuously exposed to the outdoor environment since the time of casting. Observations were made at ages of 1, 4 and 28 days. To this date no shrinkage cracking has been observed in any of the panels. There has, however, been a substantial amount of precipitation during this period and thus only limited opportunity for drying.

2.11 WATER PERMEABILITY

Two cores, 150 mm in diameter by 125 mm long, were diamond drilled from the small shotcrete test panels, from each of the six shotcrete mixes, at an age of 24 days. The test samples were wrapped in plastic and sent to CANMET's Ottawa laboratory for testing of water permeability.

3.0 CONCLUSIONS

1) This Phase II evaluation has demonstrated that it is possible to batch, mix, pump and shoot high volume fly ash, high volume polypropylene fibre reinforced wet mix shotcrete mixtures in the field, using conventional transit mix supply and wet-mix shotcrete equipment, provided the mixtures are properly designed.

2) The mixtures require a certain minimum amount of water in order to be suitable for practical field application. In Mix U a high dosage of superplasticizer was used and the water content was reduced to 108 l/m^3. This mixture, in spite of being at a flowing consistency, was too cohesive and sticky for practical field application. The water content in all the other mixtures tested was increased to be in the range of 142 to 158 l/m^3.

3) The 38 mm long FORTA CR twisted collated, fibrillated, polypropylene fibre used in this study could be readily added, mixed and dispersed by direct addition to a transit mixer. The mixtures pumped and shot well at fibre addition rates of around 3.3 kg/m^3 with no evidence of segregation or fibre balling. At higher fibre addition rates of around 6.5 kg/m^3 the mixtures were still suitable for pumping and shooting, but there was a slight tendency to segregation, with coarse aggregate particles being "thrown-out" onto the surface of the consolidated shotcrete during shooting of the large restrained shrinkage test panels. This was not viewed as a major concern, and a slight reduction in the coarse aggregate fraction and/or fibre content would tend to offset this effect.

4) Compressive strength of the leaner mixtures (nominal 420 kg/m^3 cementitious content) was around 18 to 19 MPa at 28 days on cores extracted from test panels. The richer mixtures (nominal 480 kg/m^3 cementitious content) had 28 day compressive strengths in the range of 19 to 23 MPa. There was a good correlation between water/cementitious ratio and compressive strength. Higher 28 day compressive strengths are attainable through the use of higher dosages of super-plasticizer (Mix U had a 28 day compressive strength 38 MPa). Pumping and

shooting requirements, however, place a limit on the amount of superplasticizer that can be practically used, as noted in Item 2.

5) Flexural strength generally followed the same trends as compressive strength. The best ASTM C1018 toughness index performance was attained with the rich mix (Mix Z) with 6.5 kg/m^3 polypropylene fibre. This mix met the commonly specified toughness index requirements of $I_5 \geq 3.5$ and $I_{10} \geq 5.0$. The rich mix (Mix Y) with 3.3 kg/m^3 polypropylene fibre came close to meeting these requirements. The lean mix (Mix V) with 3.1 kg/m^3 polypropylene fibre failed to meet either of the above toughness index limits.

6) Boiled absorption and permeable voids testing showed that virtually all the shotcrete was well consolidated and dense. There was a good correlation between water/cementitious ratio and the values of boiled absorption and permeable voids, with the lowest water/cementitious ratio mixtures (which had the highest compressive and flexural strengths) showing the lowest values for boiled absorption and permeable voids. Values obtained placed the shotcrete in either an "excellent" or "good" category, according to commonly accepted criteria for rating these qualities of shotcrete.

7) Large restrained shrinkage test panels were fabricated. Two restraint conditions were evaluated; shotcrete applied to slate bedded in a mortar and shotcrete applied to a loose slate. The test panels were exposed to Vancouver weather and at up to one month after fabrication no shrinkage cracks had appeared in any of the test panels. There was a considerable amount of precipitation during this period and the panels have to date experienced only limited drying. They will continue to be monitored over the next year and any cracking which develops will be reported. The panels will also enable resistance to weathering in a Vancouver winter to be monitored.

8) Freeze/thaw testing to ASTM C666 Procedure commenced at age 28 days after shooting. This testing will be continued for 300 freeze/thaw cycles and test results will be reported when the testing is completed. 56 day compressive strength tests are also still outstanding and will be reported when available.

9) Specimens cut from test panels for each of the six shotcrete mixtures have been shipped to CANMET in Ottawa for water permeability testing and evaluation of the parameters of the air void system.

In conclusion, the results of the testing completed to date look very encouraging. A final report will be issued once the 56 day compressive strength and freeze/thaw test results are available. Recommendations for final mixture designs for use in the Halifax Airport project will be provided in the final report.

Respectfully Submitted,
Hardy BBT Limited

Per:

P. McGrath, M.A.Sc., P.Eng.
Materials Project Engineer

Per: D. R. Morgan

D.R. Morgan, Ph.D., P.Eng.
Chief Materials Engineer

Reviewed by:

J. Neill, P.Eng.
Materials Engineer

PMcG:DRM:nlg

TABLE 1

ST.LAWRENCE CEMENT

1300 Ste. Anne Boulevard
Beauport, Quebec
P.O. Box 1150
Quebec, Quebec
G1K 7C9

Telephone (418) 663 7831
Telecopier (418) 663-6743
Telex 051 3009 (Laurencim Obc)

CEMENT TEST REPORT

PERIOD July 1989

SAMPLE DESIGNATION TYPE 10 MARITIMES

CHEMICAL ANALYSIS		PHYSICAL PROPERTIES	
Loss on ignition	1.44 %	Fineness :	
Insoluble residue	0.36 %	Blaine	3935 cm²/kg
Free lime	0.92 %	Passing 45 micro	94.42
		Setting time :	
Silica (SiO_2)	21.09 %	Initial	155 min.
Alumina (Al_2O_3)	4.81 %	Final	305 min.
Iron oxide (Fe_2O_3)	2.33 %	Soundness :	
Calcium oxide (CaO)	62.32 %	Autoclave expansion	0.13 %
Magnesia (MgO)	3.06 %	Air content	7.5 %
Sulphur trioxide (SO_3)	3.01 %	False set	86.7 %
Alkalis (Na_2O equivalent)	0.88 %		
		Compressive strength :	
Mineralogical composition :			
Tricalcium silicate (C_3S)	49 %	at 3 days	25.0 MPa
Dicalcium silicate (C_2S)	23 %	at 7 days	32.6 MPa
Tricalcium aluminate (C_3A)	8.8 %	at 28 days	N/A MPa
Ferro-Aluminate (C_4AF)	7.1 %		

Above results indicate that the cement represented by this sample complies with all requirements of specification CAN/CSA-A5-M88.

28 days for June 89: 38.0 MPA

Beauport, August 15, 1989

René Cossette, eng.
pp Colin Danylo, eng.
Chief Chemist

TABLE 2 - CHEMICAL AND PHYSICAL PROPERTIES OF LINGAN LOW CALCIUM FLY ASH

CHEMICAL COMPOSITION	PERCENT BY MASS
SiO_2	45.2
Al_2O_3	20.7
Fe_2O_3	24.8
CaO	1.63
MgO	0.97
TiO_2	1.05
SO_3	0.65
K_2O	2.40
Na_2O	0.59
PHYSICAL TESTS	**TEST RESULTS**
Loss on Ignition (%)	2.66
Pozzolanic Activity Index (with cement) (%)	97
Blaine Fineness (m^2/kg)	351
Percent Finer Than 45 um	84
Relative Density	2.64

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-14
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

OJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

BJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MIX NO.	U	V	W	X	Y	Z
Fibre Dosage, kg/m3 FORTA CR-38 mm	0	3.1	6.4	0	3.3	6.5
Type 10 Cement, kg/m3	161	157	158	172	174	167
Fly Ash, kg/m3	269	261	264	312	313	303
10 x 5 mm Coarse Aggregate (SSD), kg/m3	541	520	520	507	500	489
Sand (SSD), kg/m3	1267	1220	1223	1198	1185	1159
Water l/m3	108	152	149	147	142	158
Superplasticizer, l/m3 DURASAR	9.5	5.2	4.2	4.3	4.4	4.3

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-14
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

OJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

BJECT: PLASTIC SHOTCRETE PROPERTIES FOR PHASE II FIELD SHOTCRETE STUDY

MIX NO.	U	V	W	X	Y	Z
W/C + FA Ratio	0.25	0.36	0.35	0.30	0.29	0.34
Slump Before Fibre Addition, mm	220	60	135	120	115	230
Air Content Before Fibre Addition, %	9.3	10.7	12.6	9.7	8.8	12.5
Slump After Fibre Addition, mm	-	45	40	-	55	125
Air Content After Fibre Addition, %	-	10.0	9.6	-	10.8	13.7
Air Content, % (after shooting)	5.2	3.9	3.6	3.6	4.5	4.5
Ambient Temperature, °C	8	5	3	7	-	10
Shotcrete Temperature, °C	12	13	12	14	14	13

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

JECT: SHOTCRETE STUDY - HALIFAX AIRPORT

JECT: FIELD TRIAL MIXES, POLYPROPYLENE FIBRE REINFORCED HIGH VOLUME FLY ASH WET-MIX SHOTCRETE; TEST RESULTS; NOMINAL 420 kg/m3 CEMENTITIOUS

MIX NO.	U	AVG.	V	AVG.	W	AVG.
Compressive Strength 75 mm Ø Core (MPa)						
@ 7 days	18.3, 17.0	17.7	7.1, 6.8	7.0	5.4, 6.8	6.1
@ 28 days	38.1, 37.6	37.9	19.5, 18.5	19.0	18.6, 17.7	18.2
@ 56 days	- -	-	- -	-	- -	-
Compressive Strength 150 mm x 300 mm Cylinders (MPa)						
@ 7 days	15.8, 16.0	15.9	6.3, 7.3	7.3	8.0, 7.8	7.9
@ 28 days	34.3, 30.0	32.2	17.4, 16.8	17.1	16.5, 17.2	16.9
@ 56 days	- -	-	- -	-	- -	-
Flexural Strength, MPa @ 28 days	5.0,4.9,4.5	4.8	2.9,2.9,2.8	2.9	2.6,2.8,2.7	2.7
Toughness Index @ 28 days						
I_5	-	-	2.7,3.0,2.8	2.8	3.1,3.1,3.9	3.4
I_{10}	-	-	4.9,4.8,4.9	4.9	5.8,5.5,7.0	6.1
I_{20}	-	-	8.7,7.8,8.1	8.2	11.0, 9.7, 11.2	10.6
Residual Strength, %						
$RS(I_5, I_{10})$	-	-	44, 36, 42	41	54, 48, 62	55
$RS(I_{10}, I_{20})$	-	-	38, 30, 32	33	52, 42, 42	45
Boiled Absorption, %	3.4,3.3,3.4	3.4	6.3,6.2,6.3	6.3	6.7,7.7,6.8	7.1
Permeable Voids, %	7.9,7.7,7.8	7.8	13.9, 13.5 13.9	13.7	14.5, 16.2 14.5	15.1

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

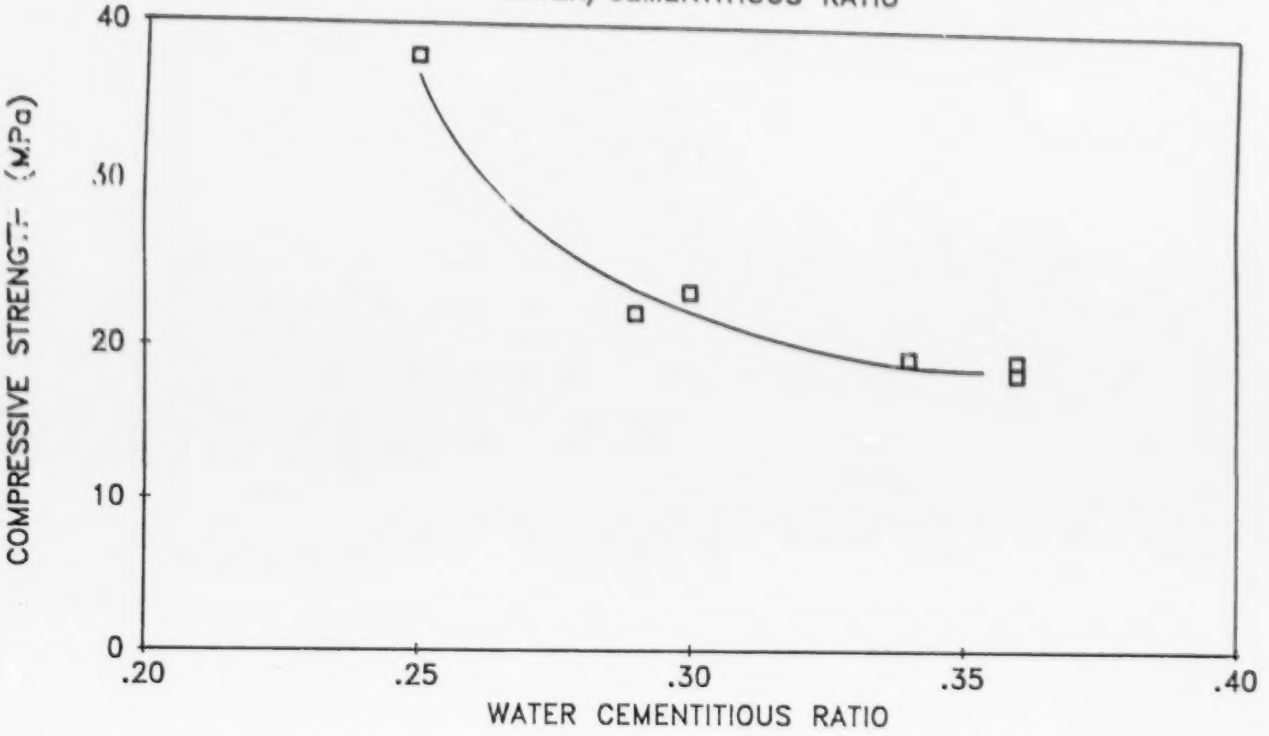
ATTENTION: Mr. John Humphries

JECT: SHOTCRETE STUDY - HALIFAX AIRPORT

JECT: FIELD TRIAL MIXES, POLYPROPYLENE FIBRE REINFORCED HIGH VOLUME FLY ASH WET-MIX SHOTCRETE; TEST RESULTS; NOMINAL 480 kg/m3 CEMENTITIOUS

MIX NO.	X	AVG.	Y	AVG.	Z	AVG.
Compressive Strength 75 mm Ø Core (MPa)						
@ 7 days	10.4, 10.0	10.2	9.4, 8.1	8.8	7.4, 7.8	7.6
@ 28 days	22.8, 24.0	23.4	21.5, 22.6	22.1	18.7, 19.7	19.2
@ 56 days	- -	-	- -	-	- -	-
Compressive Strength 150 mm x 300 mm Cylinders (MPa)						
@ 7 days	9.8, 9.7	9.8	9.4, 9.3	9.4	6.9, 6.8	6.9
@ 28 days	26.9, 21.7	24.3	20.0, 20.3	20.2	15.5, 16.1	15.8
@ 56 days	- -	-	- -	-	- -	-
Flexural Strength, MPa @ 28 days	3.4,3.4,2.9	3.2	3.4,3.1,3.1	3.2	3.3,2.7,3.3	3.1
Toughness Index @ 28 days						
I_5	-	-	3.0,3.5,3.6	3.4	3.8,3.9,3.5	3.7
I_{10}	-	-	5.4,6.1,6.1	5.9	7.8,7.5,6.4	7.2
I_{20}	-	-	9.1, 11.0, 10.4	10.2	12.8, 13.9 11.8	12.8
Residual Strength, %						
$RS(I_5, I_{10})$	-	-	48, 52, 50	50	80, 72, 58	70
$RS(I_{10}, I_{20})$	-	-	37, 49, 43	43	50, 64, 54	56
Boiled Absorption, %	5.1,5.1,5.4	5.2	6.1,5.4,5.8	5.8	6.7,6.8,6.6	6.7
Permeable Voids, %	11.5, 11.5 11.9	11.7	13.3, 12.1 12.9	12.7	14.5, 14.7 14.4	14.5

RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH OF 75 mm DIAMETER CORES AND WATER/CEMENTITIOUS RATIO



REVISIONS	Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES	FIGURE 1
REFERENCES		

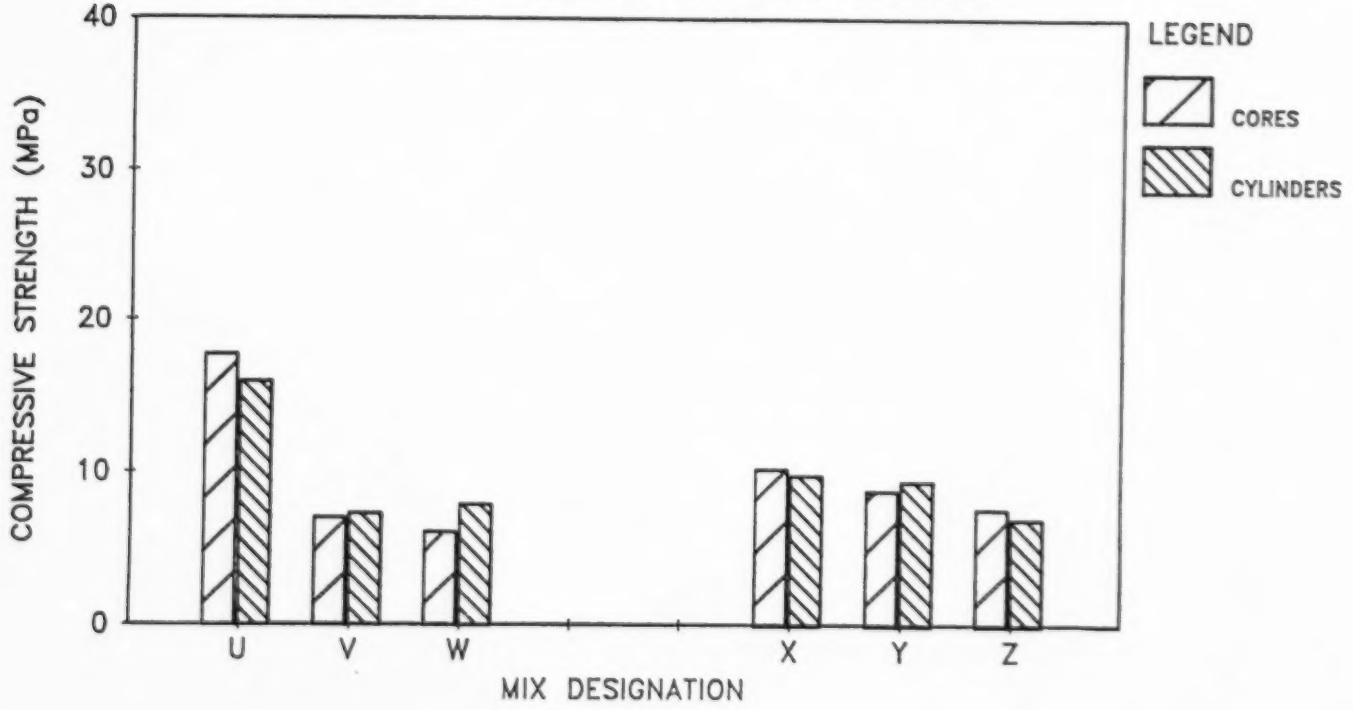
SCALE	DATE DEC 20/89	MADE P.Mc	CHKD	JOB No VA 01584	FIGURE

HBLT 53-87 11

APPENDIX D

APPENDIX B

COMPARISON OF 7 DAY COMPRESSIVE
STRENGTH OF 75 mm DIAMETER CORES TO
150 X 300 mm MOULDED SHOTCRETE CYLINDERS

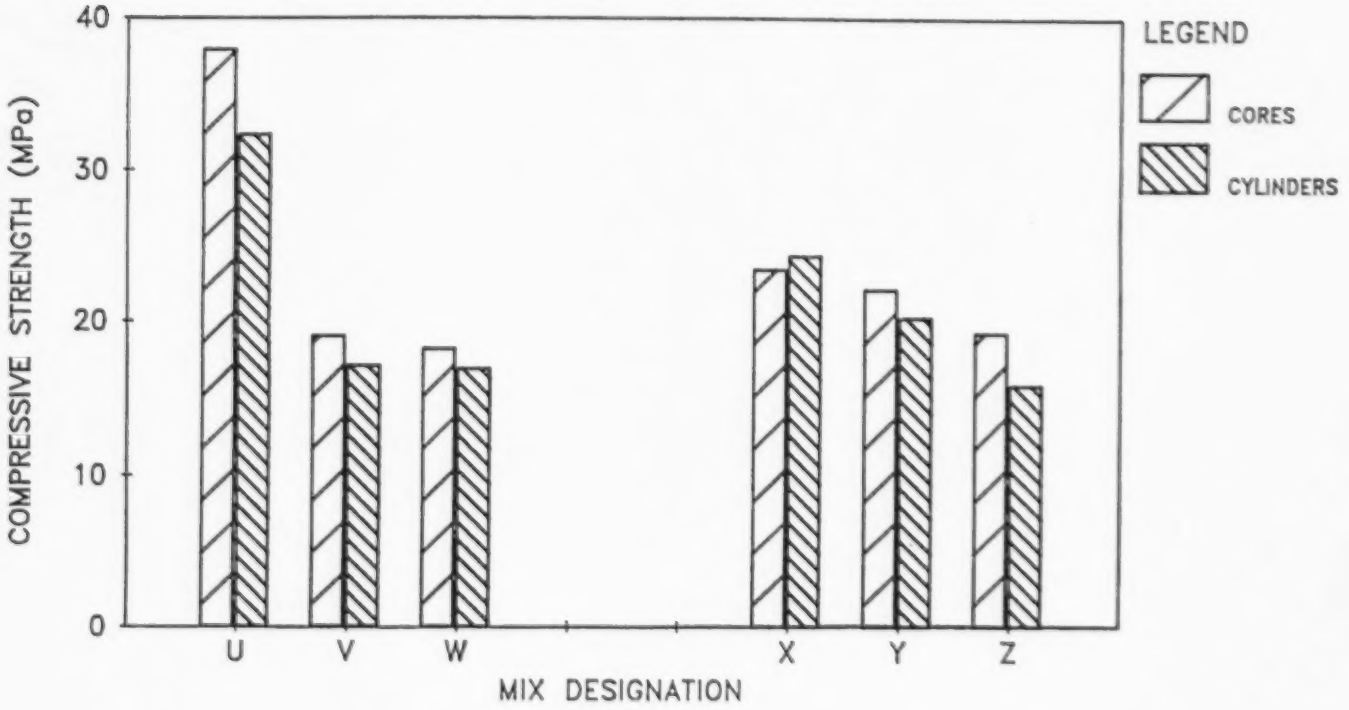


REVISIONS	Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES					FIGURE 2
REFERENCES	SCALE	DATE DEC 18/89	MADE P.M^c	CHKD	JOB No VA 91584	FIGURE

HBLT 03-87 11

APPENDIX B APPENDIX D

COMPARISON OF 28 DAY COMPRESSIVE
STRENGTH OF 75 mm DIAMETER CORES TO
150 X 300 mm MOULDED SHOTCRETE CYLINDERS



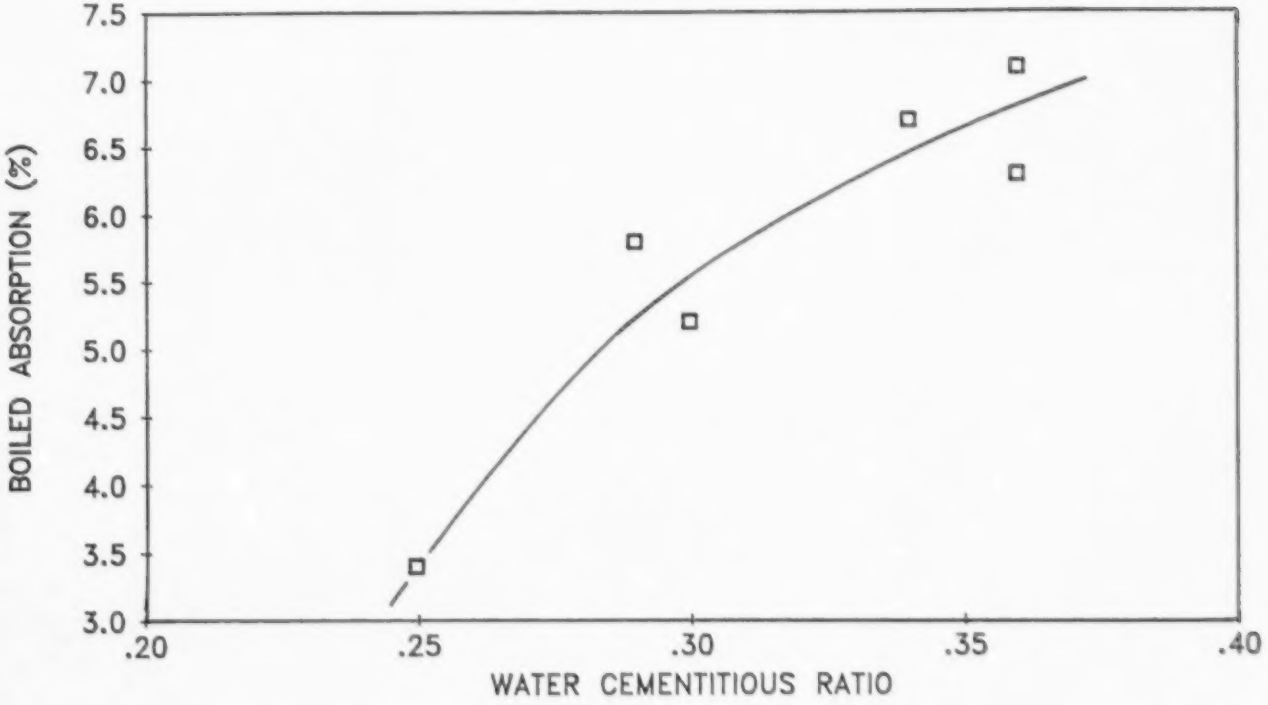
REVISIONS	Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES	FIGURE 3
REFERENCES		

SCALE	DATE DEC 18/89	MADE P.M.	CHKD	JOB No. VA 01584	FIGURE

HBLT 53-87 11

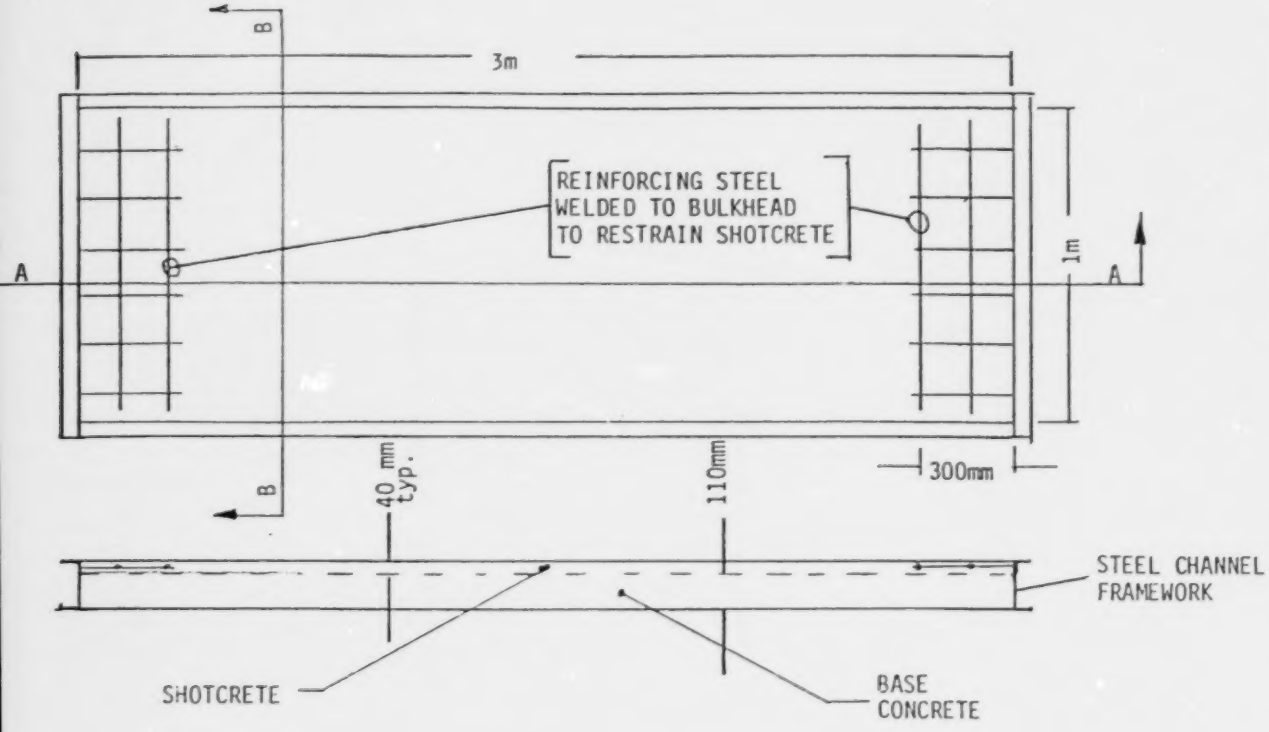
APPENDIX B

RELATIONSHIP BETWEEN BOILED ABSORPTION
AND
WATER/CEMENTITIOUS RATIO

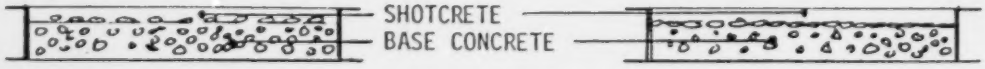


REVISIONS	Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES					FIGURE 4
REFERENCES	SCALE	DATE DEC 20/89	MADE P.M.C	CHKD	JOB No VA 01584	FIGURE

HBLT 53-87 11



SECTION A-A



UNBONDED TEST ASSEMBLAGE
polyethelene sheet covered
with loose shale

BONDED TEST ASSEMBLAGE
shale embedded in base
concrete

SECTION B-B

Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES	Figure 5 DETAILS OF RESTRAINED SHRINKAGE TEST			
	Scale N/A	Date 88.06.20	Drawn By N. McA	

TECHNICAL REPORT #B1

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIEVE ANALYSIS REPORT

SCIENCE & PROFESSIONAL SERVICES DIR.
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

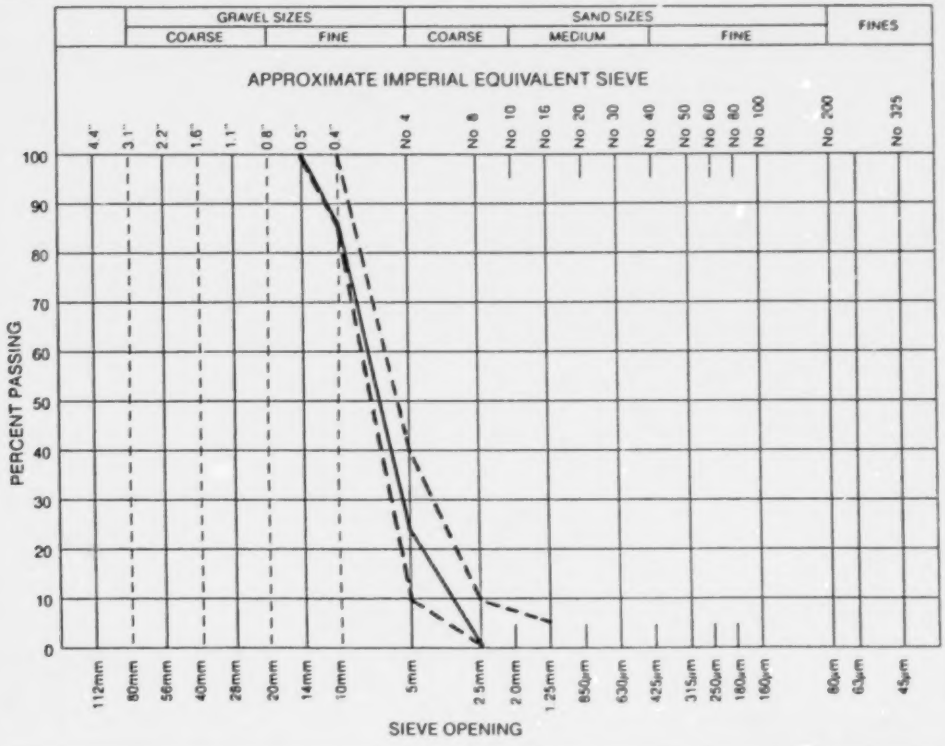
ATTENTION: Mr. W. John Humphries

OJECT SHOTCRETE STUDY - HALIFAX AIRPORT

MPLE I.D. Target TYPE OF SAMPLE 10 mm Aggregate SAMPLED BY D. Hatch

TE SAMPLED DATE RECEIVED DATE TESTED

URCE



SIEVE SIZE	PERCENT PASSING
1/2"	100.0
3/8"	86.6
No. 4	24.4
No. 8	0.4

MPLE DESCRIPTION: 10 mm shotcrete aggregate from Target Products Ltd., Burnaby, B.C.

COMMENTS 10 mm Shotcrete Aggregate Plotted vs CAN3-A23.1-M77, Table 3; Group I
10 - 2.5 mm Envelope

Hardy BBT Limited
Per D. L. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is

APPENDIX C
APPENDIX D

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B2

SIEVE ANALYSIS REPORT

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

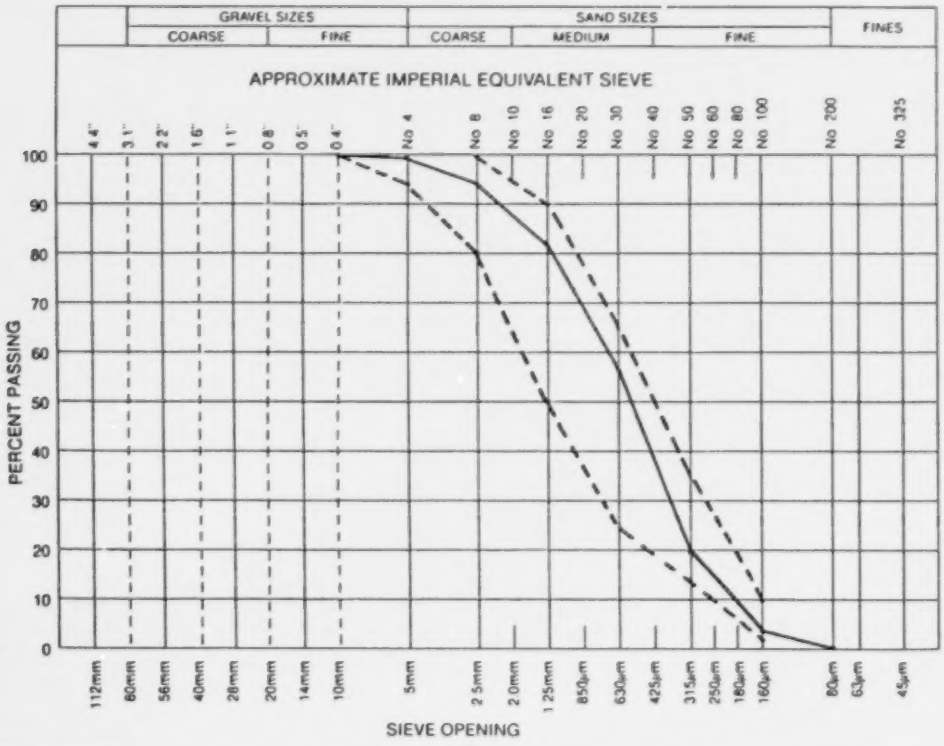
ATTENTION: Mr. W. John Humphries

OJECT SHOTCRETE STUDY - HALIFAX AIRPORT

MPLE I.D. Target | TYPE OF SAMPLE Sand | SAMPLED BY D. Hatch

E SAMPLED | DATE RECEIVED | DATE TESTED

URCE



SIEVE SIZE	PERCENT PASSING
3/8"	100.0
No. 4	99.1
No. 8	93.8
No. 16	89.1
No. 30	56.7
No. 50	19.6
No.100	3.4
No.200	0.5

AMPLE DESCRIPTION: Shotcrete sand from Target Products Ltd., Burnaby, B.C.

COMMENTS Sand Gradation Plotted vs. CAN3-A23.1-M77, Table 1 Fine Aggregate Gradation Envelope

Hardy BBT Limited
Per D. R. Morgan

Reporting of these test results is for information purposes only. Engineering interpretation or evaluation of the test results is provided only on written request.

APPENDIX C

APPENDIX D

TECHNICAL REPORT #B3

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIEVE ANALYSIS REPORT

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

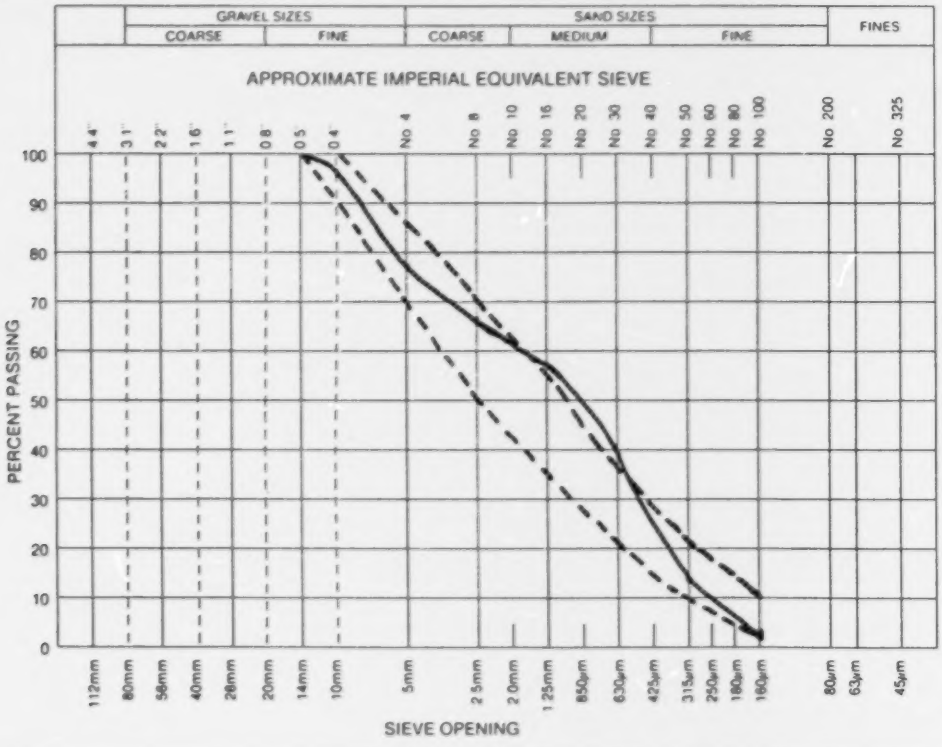
ATTENTION: Mr. John Humphries

OJECT SHOTCRETE STUDY - HALIFAX AIRPORT

MPLE I.D. Target TYPE OF SAMPLE Combined SAMPLED BY D. Hatch

TE SAMPLED DATE RECEIVED DATE TESTED

URCE



SIEVE SIZE	PERCENT PASSING
1/2"	100.0
3/8"	96.0
No. 4	76.7
No. 8	65.8
No. 16	57.5
No. 30	39.7
No. 50	13.7
No. 100	2.4
No. 200	0.4

AMPLE DESCRIPTION: Combined blend of 70:30 :: Sand:10 mm Coarse Aggregate by Mass

COMMENTS Combined Blend Shown Vs. ACI 506R-85, Table 2.2.1, Gradation No. 2 Envelope

Hardy BBT Limited
Per D. R. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written request.

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SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

JECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX U

JECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	161	3150	0.0512
Fly Ash (Type F)	269	2640	0.1019
Coarse Aggregate (SSD) 10 mm x 5 mm	541	2707	0.1997
Sand (SSD)	1267	2652	0.4777
Water	108	1000	0.1080
Water Reducing Admixture DURASAR (ml/100 kg)	2200	1000	0.0095
Air Content (as shot)	5.2		0.0520
TOTALS:	2348		1.0000

Sand Content = Ps = 70%

Approximate W/(C + FA) RATIO = 0.25

Theoretical Plastic Density = 2348 kg/m^3

APPENDIX C

APPENDIX D

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

OJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX V

BJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	157	3150	0.0498
Fly Ash (Type F)	261	2640	0.0987
Coarse Aggregate (SSD) 10 mm x 5 mm	520	2707	0.1920
Sand (SSD)	1220	2652	0.4600
Fibre (Polypropylene)	3.1	920	0.0034
Water	152	1000	0.1519
Water Reducing Admixture DURASAR (ml/100 kg)	1250	1000	0.0052
Air Content (as shot)	3.9		0.0390
TOTALS:	2318		1.0000

Sand Content = Ps = 70.1%

Approximate W/(C + FA) RATIO = 0.36

Theoretical Plastic Density = 2318 kg/m^3

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

ECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX W

ECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	158	3150	0.0502
Fly Ash (Type F)	264	2640	0.1000
Coarse Aggregate (SSD) 10 mm x 5 mm	520	2707	0.1921
Sand (SSD)	1223	2652	0.4612
Fibre (Polypropylene)	6.4	920	0.0069
Water	149	1000	0.1490
Water Reducing Admixture DURASAR (ml/100 kg)	995	1000	0.0042
Air Content (as shot)	3.6		0.0360
TOTALS:	2325		1.0001

Sand Content = Ps = 70.2%

Approximate W/(C + FA) RATIO = 0.35

Theoretical Plastic Density = 2325 kg/m^3

APPENDIX C

APPENDIX D

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

JECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX X

JECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	172	3150	0.0546
Fly Ash (Type F)	312	2640	0.1181
Coarse Aggregate (SSD) 10 mm x 5 mm	507	2707	0.1872
Sand (SSD)	1198	2652	0.4518
Water	147	1000	0.1470
Water Reducing Admixture DURASAR (ml/100 kg)	893	1000	0.0043
Air Content (as shot)	3.7		0.0370
TOTALS:	2340		0.9999

Sand Content = Ps = 70.3%

Approximate W/(C + FA) RATIO = 0.30

Theoretical Plastic Density = 2340 kg/m^3

APPENDIX C

APPENDIX D

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

ECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX Y

ECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	174	3150	0.0551
Fly Ash (Type F)	313	2640	0.1187
Coarse Aggregate (SSD) 10 mm x 5 mm	500	2707	0.1847
Sand (SSD)	1185	2652	0.4466
Fibre (Polypropylene)	3.3	920	0.0035
Water	142	1000	0.1420
Water Reducing Admixture DURASAR (ml/100 kg)	901	1000	0.0044
Air Content (as shot)	4.5		0.0450
TOTALS:	2322		1.0000

Sand Content = Ps = 70.3%

Approximate W/(C + FA) RATIO = 0.29

Theoretical Plastic Density = 2322 kg/m^3

APPENDIX C
APPENDIX D

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

JECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX Z

JECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	168	3150	0.0533
Fly Ash (Type F)	303	2640	0.1148
Coarse Aggregate (SSD) 10 mm x 5 mm	489	2707	0.1807
Sand (SSD)	1159	2652	0.4368
Fibre (Polypropylene)	6.5	920	0.0071
Water	158	1000	0.1580
Water Reducing Admixture DURASAR (ml/100 kg)	916	1000	0.0043
Air Content (as shot)	4.5		0.0450
TOTALS:	2288		1.0000

Sand Content = Ps = 70.3%

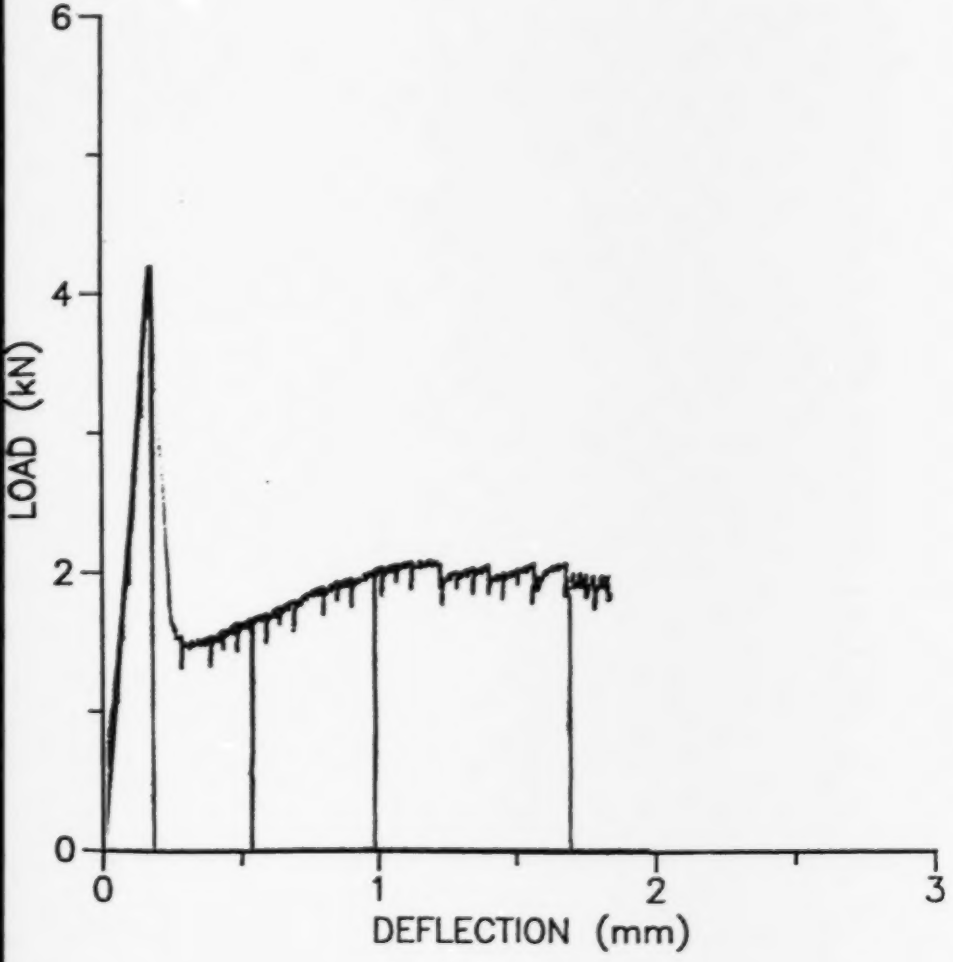
Approximate W/(C + FA) RATIO = 0.34

Theoretical Plastic Density = 2288 kg/m^3

APPENDIX C
APPENDIX D

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: V–A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.3 kg/m³



APPENDIX D

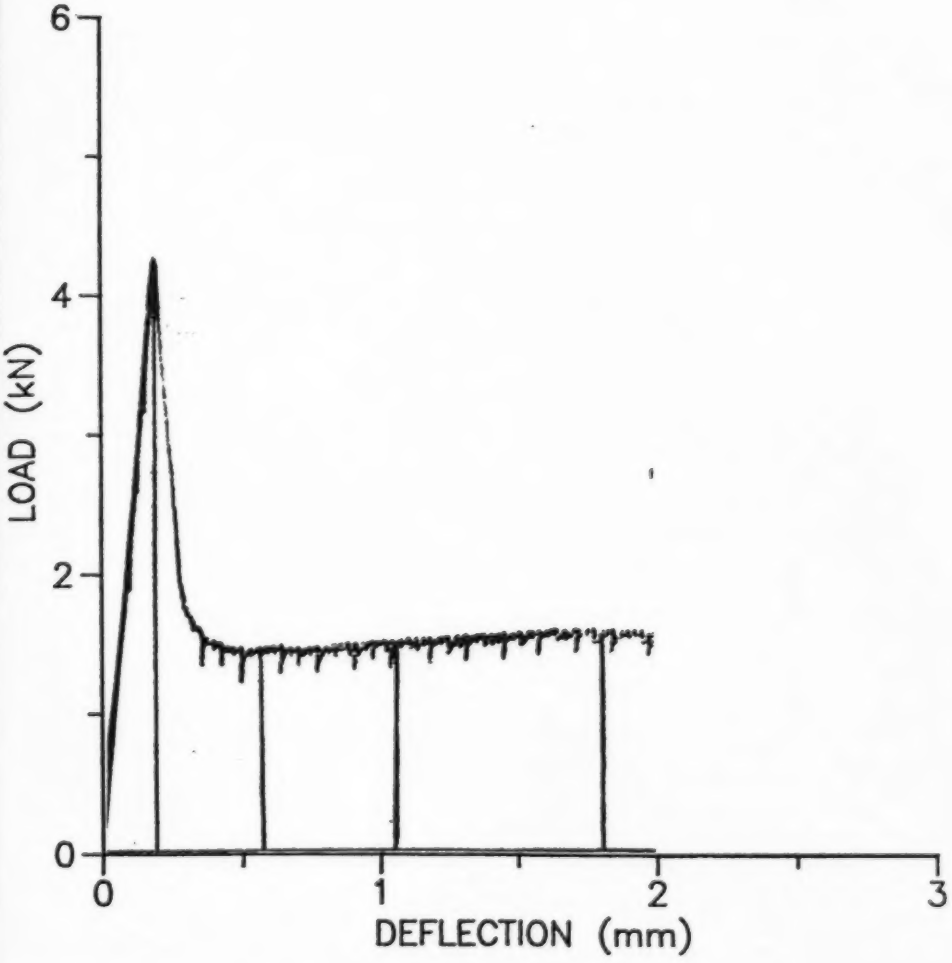
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018–85

SPECIMEN NO.: V–B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.3 kg/m³



APPENDIX D

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

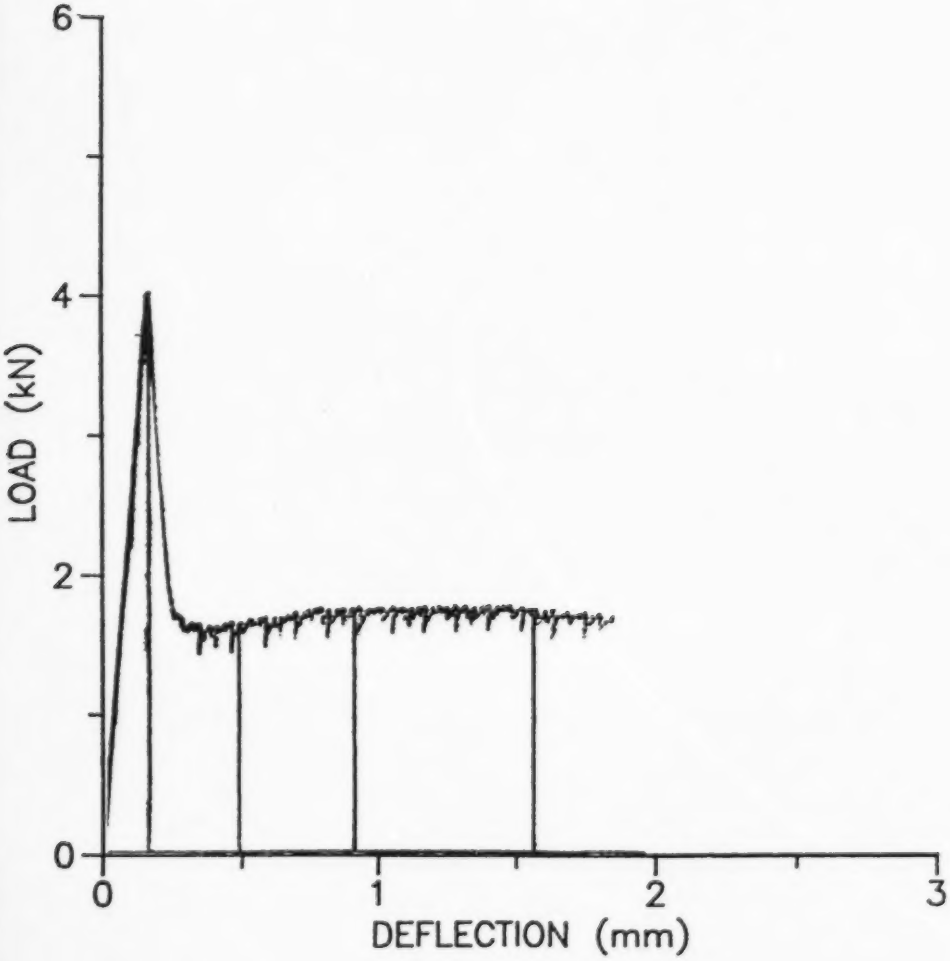
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

E N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

7/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: V–C AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.3 kg/m^3



APPENDIX D

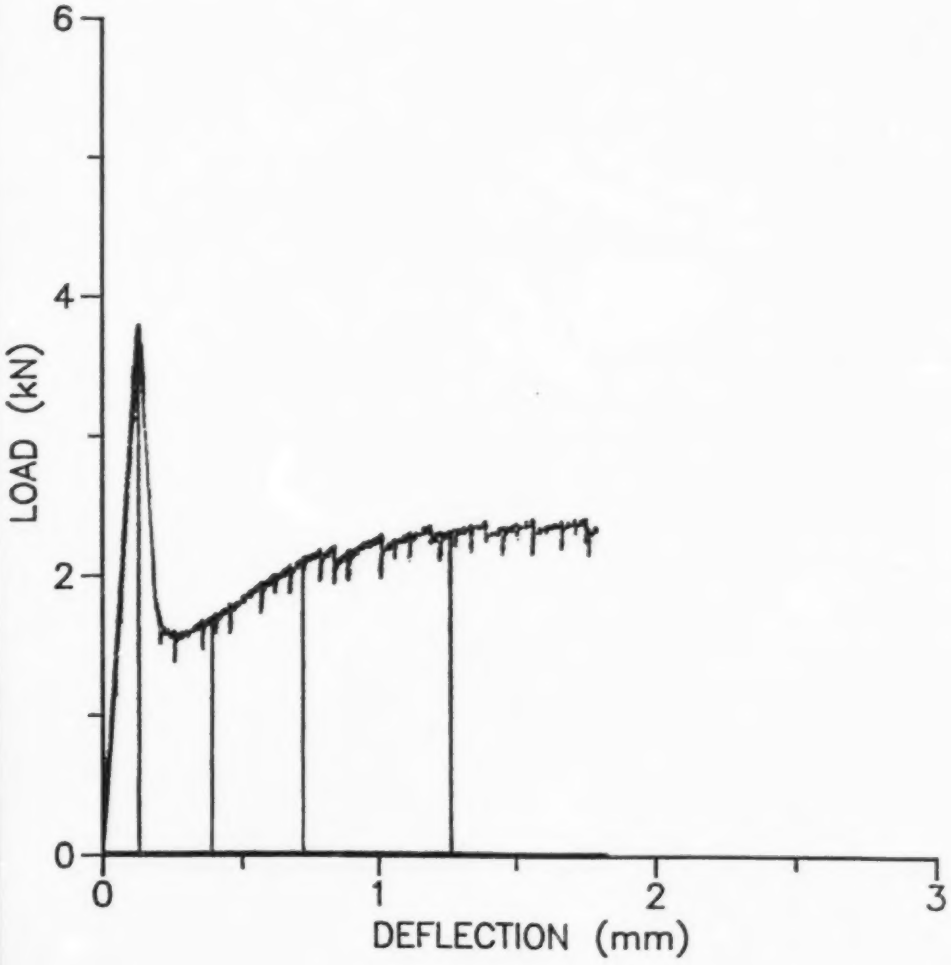
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

E N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: W–A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.4 kg/m³



APPENDIX D

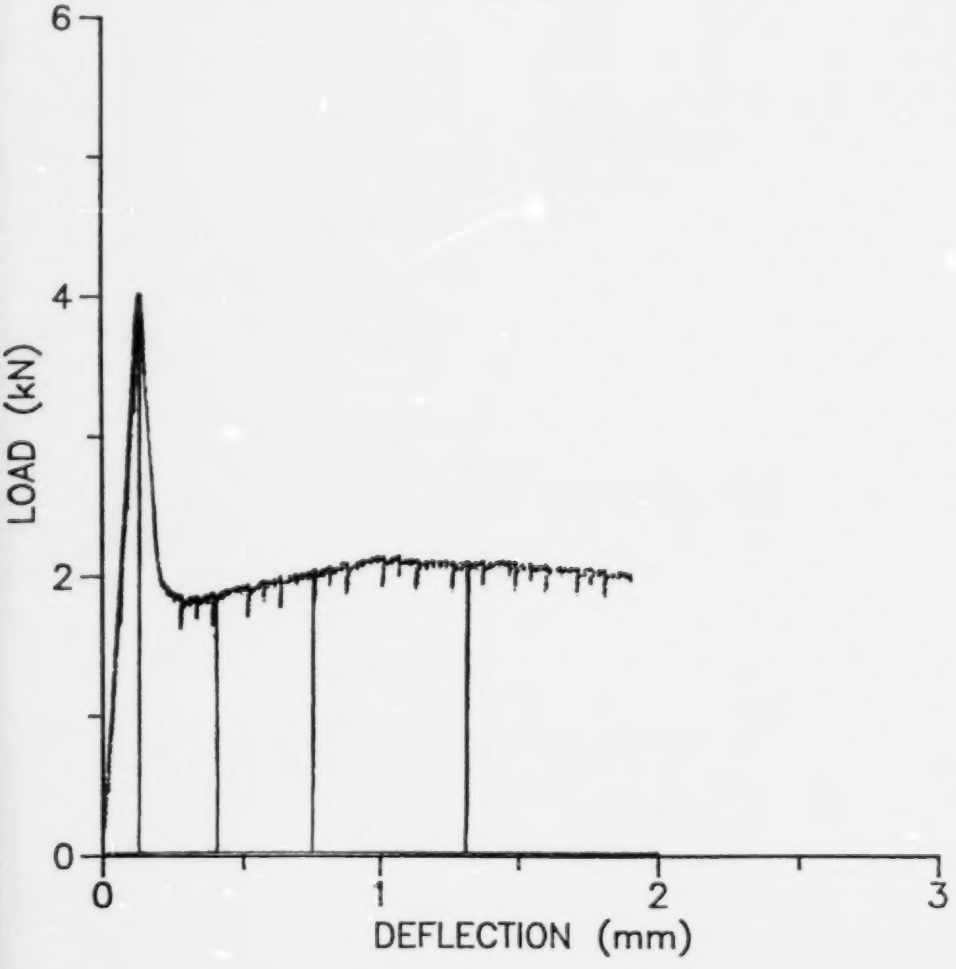
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: W–B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.4 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

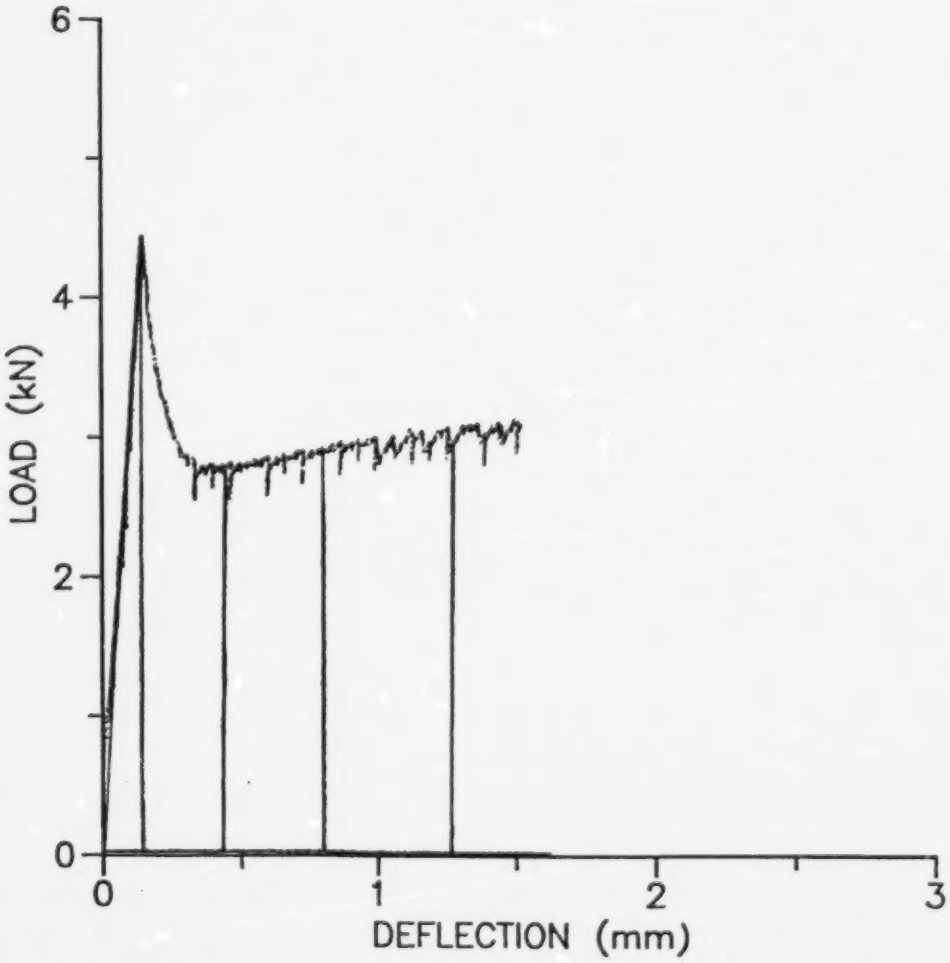
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

APPENDIX D

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: W–C AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.4 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

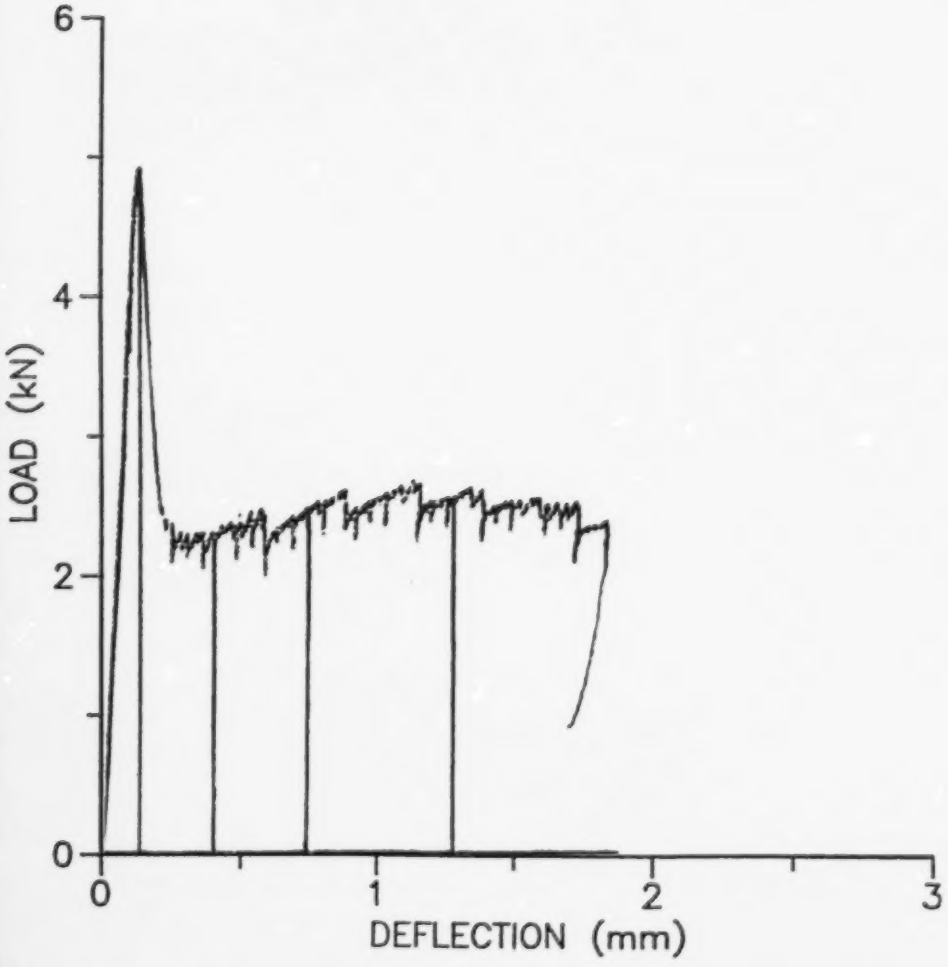
LE N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

87/11

APPENDIX D

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: Y–A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.1 kg/m³



APPENDIX D

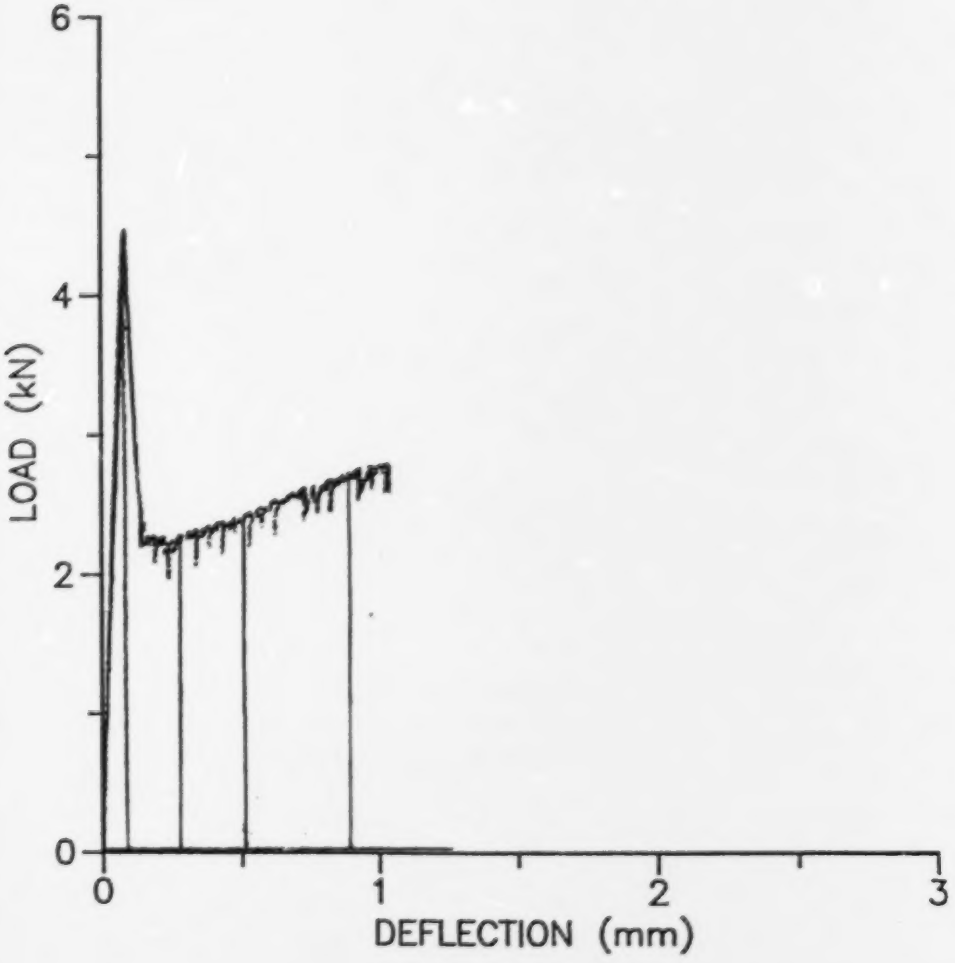
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018–85

SPECIMEN NO.: Y–B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.1 kg/m³



APPENDIX D

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

LE N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018–85

SPECIMEN NO.: Y–C AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
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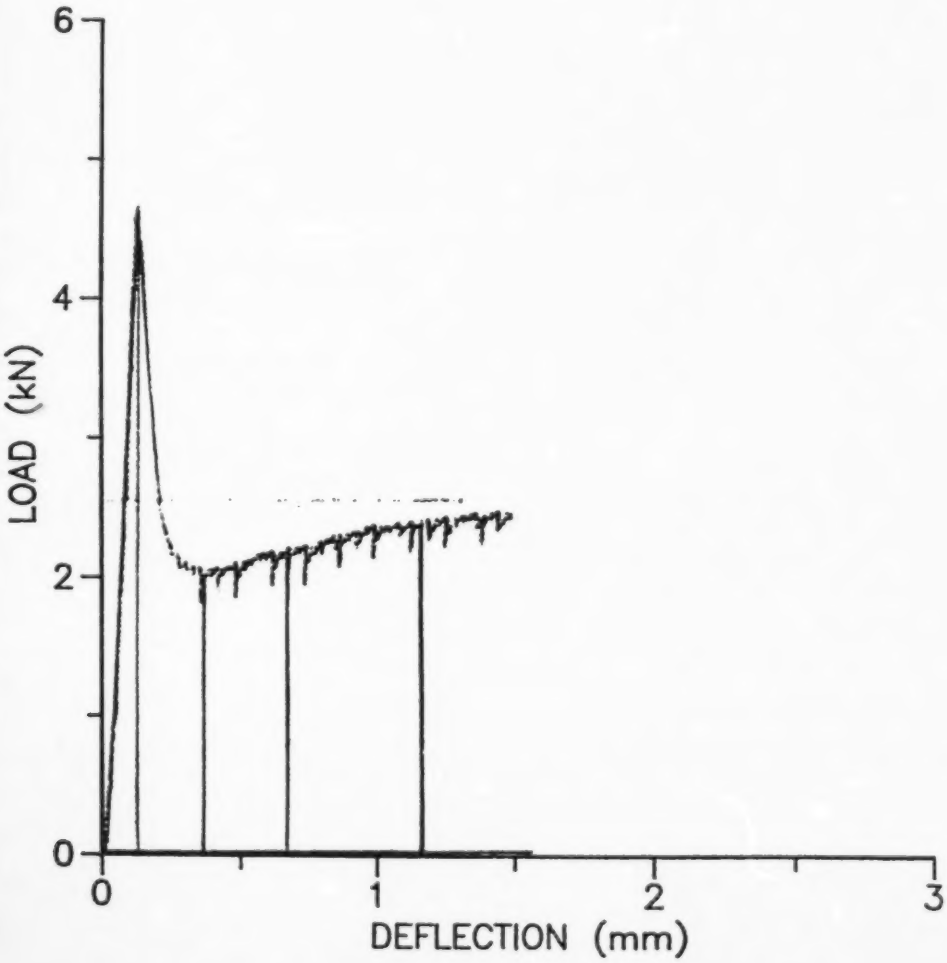
FIBRE DOSAGE: 3.1 kg/m³



APPENDIX D

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
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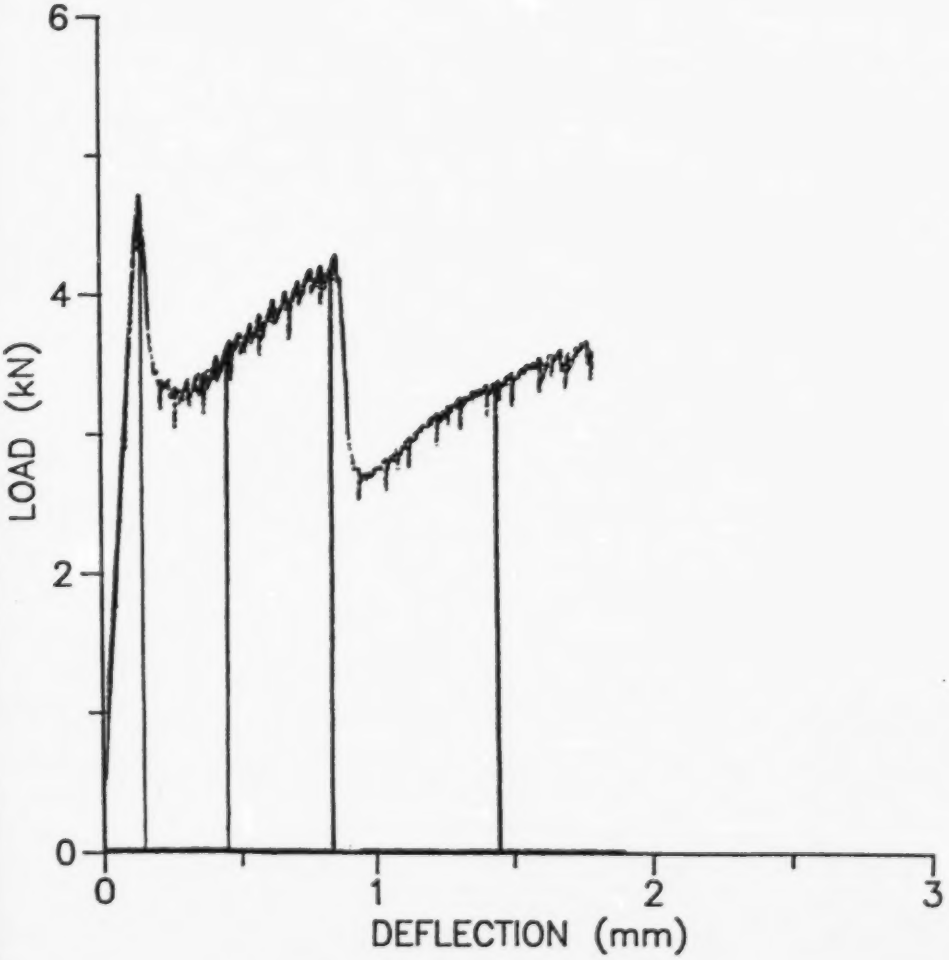
JOB NO.: VA1584

E N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: Z–A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.5 kg/m³



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PROJECT: HIGH VOLUME FLY ASH PFRS
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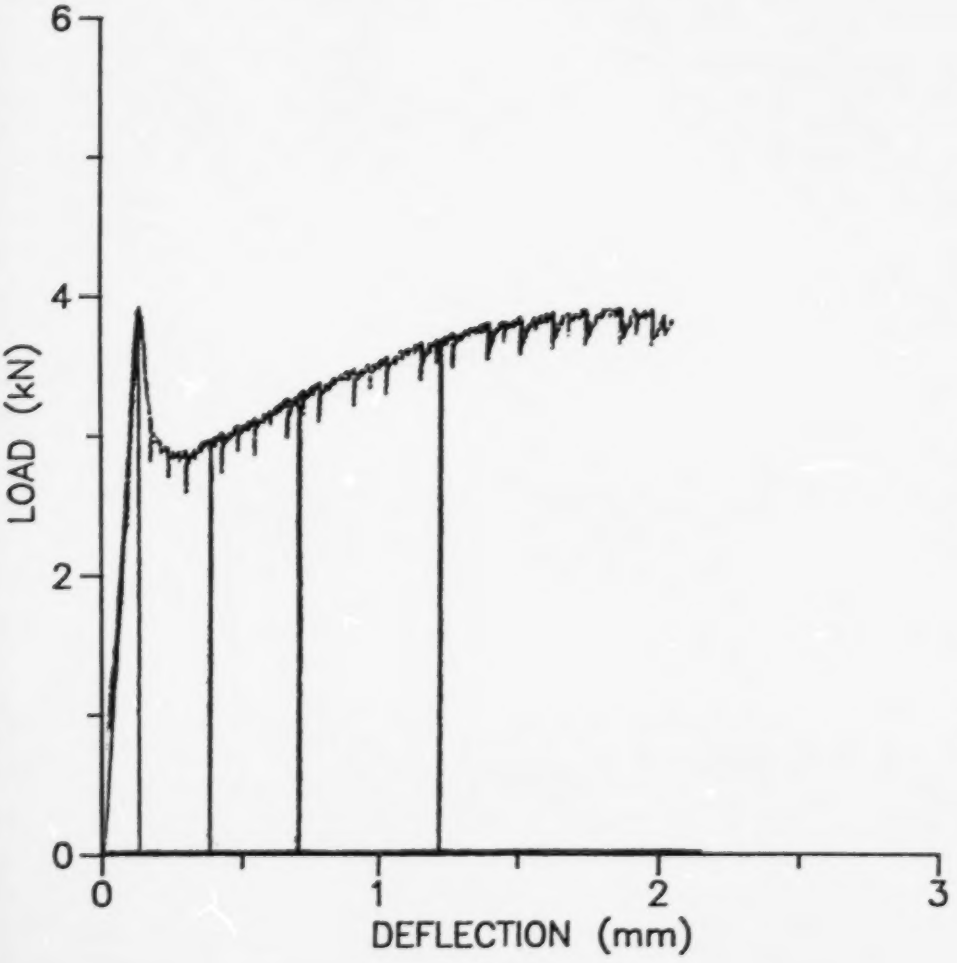
JOB NO.: VA1584

E N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

APPENDIX D

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018–85

SPECIMEN NO.: Z–B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.5 kg/m³



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Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

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N.T.S.	DATE 89–12–12	MADE D.H.	CHKD.	JOB No.	FIGURE

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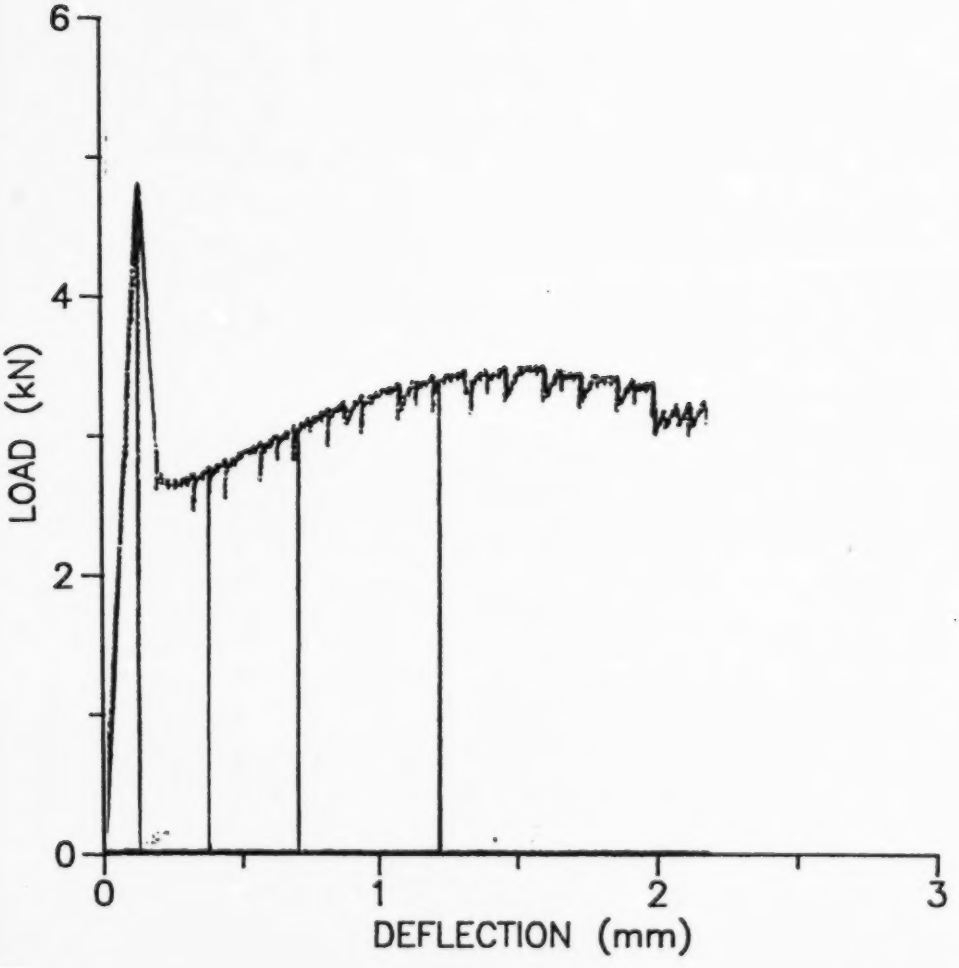

APPENDIX D

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
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SPEC-DATA®

This Spec-Data sheet conforms to editorial style prescribed by The Construction Specifications Institute. The manufacturer is responsible for technical accuracy.

1. PRODUCT NAME

FORTA™ CR® (Concrete Reinforcement)

2. MANUFACTURER

FORTA Corporation
100 Forta Drive
Grove City, PA 16127-9990
Phone: 1-800-245-0306
1-800-222-8907 in PA
1-412-458-5221
Telex: 812 535 FORTA GRCT
FAX: 412-458-8331

3. PRODUCT DESCRIPTION

General Description: FORTA CR is a twisted bundle, CFP (collated fibrillated polypropylene) fibrous reinforcement.

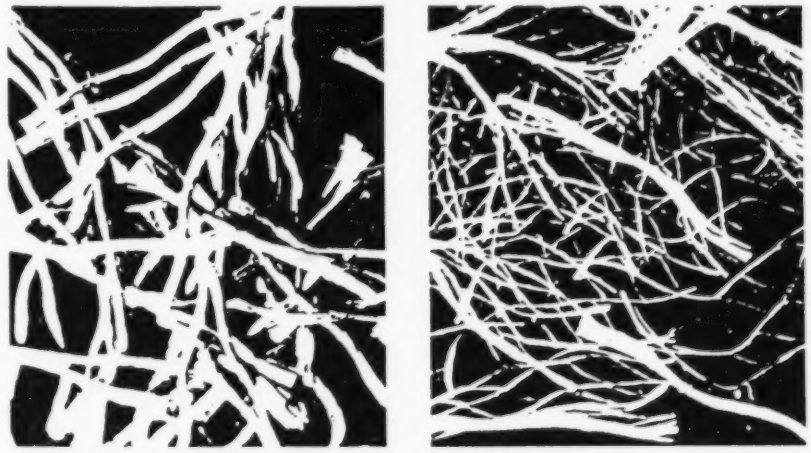
Basic Use: FORTA CR is used as a secondary, crack-controlling reinforcement for concrete. FORTA CR may be used to replace welded wire fabric (wire mesh) in any application where the mesh is used as temperature/shrinkage reinforcement.

General Applications: Major application areas for FORTA CR include cast-in-place concrete, air-placed concrete, and precast concrete elements.

Cast-in-place applications include industrial floors, parking lots, pavements, and residential concrete. Air-placed applications include water reservoir liners, irrigation ditches, tunnel and culvert liners, man-made rock and waterscapes, and bridge deck overlays. Precast concrete uses include wall panels, septic tanks, vaults, and various ornamental products.

Benefits: From an economic standpoint, the use of FORTA CR eliminates the costs associated with the handling and placement of wire mesh in both site-cast and precast applications. From a technical value-added standpoint, the uniform, three-dimensional fibrous distribution allows FORTA CR to control cracking better than the single-plane layer of wire mesh. The single purpose of wire mesh, when used as secondary/temperature reinforcement, is to hold the concrete together *after* it cracks. Due to the uniform fibrous reinforcement coverage, FORTA CR not only controls the cracking process more effectively, but also contributes to a number of additional concrete properties.

The additional benefits of FORTA CR include the reduction of plastic and hardened concrete shrinkage and permeability, and improved impact resistance, ductility, fatigue strength, and toughness. Also, test data per ASTM C-944 shows that FORTA CR significantly reduces floor surface abrasion as compared to plain concrete.



Twisted FORTA™ CR® bundles spring open during mixing.

Limitations: FORTA CR is considered as a secondary reinforcement. FORTA CR will not replace primary reinforcement intended to support structural loads. FORTA Corporation's engineering group will assist in evaluating any potential application.

Dosage Rates: FORTA CR is packaged in 1.6 pound bags, which is the recommended quantity for one cubic yard of concrete. For metric applications, FORTA CR is packaged in one kilogram bags. These dosage rates have been determined by engineering testing and by extensive use of FORTA CR in conventional applications where wire mesh is being replaced as a secondary reinforcement. Higher volumes per cubic yard have shown improvement to the toughness index of the fibrous concrete—consult FORTA Corporation for additional details.

Four twisted fibrous bundle lengths are manufactured by FORTA Corporation. The fibrous bundle length is matched with the maximum top-size of the coarse aggregate used in the mix. The effective bond length of a fibrous reinforcement is approximately 50% of the actual bundle length. Therefore, resistance to pull out/debonding and the utilization of the material's ultimate tensile strength are realized when the longest bundle length that can be properly mixed and uniformly distributed in a given mix is specified. (See bundle length per aggregate size chart in Table 1.)

Table 1

PRODUCT TYPE	BUNDLE LENGTH	AGGREGATE TOP-SIZE	AASHTO SIZE
A-5	¾"	¼" –	10 –
A-10	1½"	½"	8 –
D-15	2¼"	¾"	67 –
D-24	2½"	1" +	57 +

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Approvals—Specifications: For precast septic tank and water distribution box products, FORTA Corporation has obtained approvals from numerous state and local agencies for use as secondary/handling reinforcement in lieu of wire mesh. (Contact FORTA Corporation for specific approvals.) For flatwork, both I.C.B.O. Evaluation Report #4151 (in compliance with the 1985 Uniform Building Code) and FORTA's U.S.-GSA Contract #G.S.-00F-79582 (for federal government purchase) are available to the architect and engineer upon request.

FORTA Corporation suggests that current consensus standards and practices be followed in the design, placing, and finishing of concrete.

4. TECHNICAL DATA

Chemical: FORTA CR consists of a virgin homo-polymer polypropylene in combination with other chemicals and additives defined by FORTA Corporation to meet precise engineering standards. FORTA CR is chemically inert and non-hazardous in the form supplied. FORTA CR will not react with any components found within the concrete, such as chemical admixtures, alkalis, or calcium chloride, and will not rot or corrode. Also, FORTA CR will not react with the components used to cure and seal the concrete, nor with the vast majority of materials that may come in contact with the concrete including organic acids. FORTA CR also contains a color additive to facilitate camouflaging with cured concrete and to enhance the surface U.V. stability. Both the FORTA Technical Report: Chemical Resistance of FORTA CR Fibrous Reinforcement and the O.S.H.A. Material Safety Data Sheet #20 (in voluntary, non-required compliance with O.S.H.A. Hazard Communication Standard, 29 CFR 1910.1200) are available upon request.

Physical Properties: Due to the chemically inert nature of FORTA CR and subsequent need for mechanical fibrous bonding with the cement matrix, FORTA Corporation utilizes a manufacturing process that is engineered solely to enhance the bonding of the FORTA in the concrete matrix. FORTA CR's fibrillation pattern (screen formation) is comprised of coarse main fibrils and lesser diameter connecting fibrils. This method reduces the risk of fibrous debonding and pull-out from the concrete matrix that would occur with small diameter unidimensional screen or monofilament fiber products.

Additional physical characteristic data include:

Specific Gravity	0.91
Density	56 lbs./cu. ft.
Modulus of Elasticity	0.70×10^6 p.s.i.
Tensile Strength	70,000 p.s.i. (Minimum)
Lengths	¼", 1½", 2¼", 2½"
Volume at 1.6 lb./cu. yd.	0.1%
Elongation at Break	8%
Per ASTM E84-80	
Flame Spread Index	1.6
Fuel Contribution	0.0
Smoke Density	0.0

5. INSTALLATION

Addition/Mixing Procedures: FORTA CR is very easy to add—one pre-weighed bag per cubic yard of concrete. It may be added with the coarse and fine aggregates at the batch plant, or directly to the mixer on the job site. When added at the batch plant with the other ingredients, no additional site mixing time is required. If added to the already mixed concrete, approximately three to five minutes of mixing are required. If a superplasticizer is used with the FORTA CR at 1.6 lb. per cubic yard, add and mix the FORTA CR first. We suggest that when adding FORTA CR to a ready mix truck, the concrete should be brought to the back of the mixer, especially if the drum contains less than 50% of capacity (i.e. for 4 cubic yards in a 10 yard capacity drum, back the concrete up to top of discharge and empty FORTA CR on top of concrete before mixing). Due to the twisted bundle configuration, it is not necessary to sprinkle or "ribbon" the FORTA CR into the mixing system.

The FORTA CR reinforced concrete can be mixed and pumped or air-placed with no special equipment necessary.

If a conventional slump test is required, perform the test in accordance with ASTM C143 prior to adding the FORTA CR. Using this conventional slump test will indicate a lower test value for fibrous concrete than for plain concrete with the same w/c ratio. If preferred, ASTM C995 can be used to measure the consistency and actual flowability of the fibrous reinforced concrete.

NOTE: Fibrous reinforced specimens should be externally vibrated and not internally rodded per ACI Committee 544 recommendations.

6. AVAILABILITY AND COST

Availability: FORTA CR can be purchased domestically and internationally. In the United States, orders are shipped from the factory within 24 hours by UPS, commercial carrier, or air freight.

Cost: The in-place cost (4" thick slab) is approximately $0.10 per square foot. Exact delivered costs may be obtained from a local FORTA dealer or from FORTA Corporation.

7. WARRANTY

FORTA CR is warranted to be free of defects and to meet all quality control standards set by the manufacturer. FORTA Corporation has no control over the design, production, placement, or testing of the concrete products in which FORTA CR is incorporated, therefore FORTA Corporation assumes no responsibility for the end products.

8. MAINTENANCE

Not applicable.

9. TECHNICAL SERVICES

Complete technical services and assistance are available by contacting the FORTA Corporation engineering group, or the local FORTA technical representative.

10. FILING SYSTEMS

SPEC-DATA® II

Sweet's Engineering Catalogue #03200/FOR

I.C.B.O. Evaluation, Report #4151

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HANDY

745, Ste-Rose St., La Prairie, Qué. J5R 1Z2

DURASAR
SUPER PLASTICIZER FOR CONCRETE

- DURASAR is a cost effective non-alkaline, extremely low sulfate and chloride free Superplasticizer. It is an efficient fluidifier and a high range water reducer agent (Superplasticizer) thereby contributing excellent rheological properties to concrete.
- DURASAR improves the flow properties of the mixture by breaking up cement agglomerates to produce lower viscosities.
- DURASAR Superplasticizer concrete does not show a high rate of slump loss.
- DURASAR will increase the mechanical properties of concrete; i.e. compressive and flexural strengths and modulus of elasticity.
- DURASAR's dispersion effect on cement particles improves the efficiency of hydration.

DURASAR can be used to produce:

- Flowing self-levelling concrete
- High early strength concrete
- Low water-to-cement ratio
- Very high strength concrete (100 MPa - 15,000 psi)
- Reduced water requirements by 20%-30%

- DURASAR can be used for:

  Pumping concrete
  Underwater applications
  Gunite applications
  Special shaped concrete slabs
  Precasting
  Architectural concrete

- DURASAR should be used for production of:

  Commercial concrete
  Fly ash concrete
  Blast furnace slag cement concrete
  Lightweight concrete
  Numerous cementitious systems

DURASAR meets the requirements of the Canadian Standards Specifications CAN3-A266.6-M85 Superplasticizing Admixtures for Concrete.

DATA
DONNÉES

DOSAGE:

DURASAR is normally used at a rate of 0.5-2.0 litres per 100 kg. (9.0-20.0 fluid oz. per 100 lb.) of cement. Other dosages may be required depending on specific conditions.

TYPICAL PROPERTIES:

Chemical classification:	Naphthalene sulfonate calcium salt
Appearance:	Clear, brown liquid
Active content:	38.0% ± 1.0%
Sulfate percentage:	0.20% ± 0.05%
pH 10% solution	7.5 ± 0.5
Specific gravity at 23° C.	1.19 ± 0.02
Freezing point	-4.0° C. (25° F)
Chlorides	Nil
Ionic nature	Anionic
Solubility, aqueous	Clear, instantly in hard, or soft water

WORKABILITY:

DURASAR fluidified concrete remains workable for approximately one hour at 20° C. (68° F). The duration of workability depends not only on temperature, but also on the type and brand of cement, the nature of the aggregates and the method of transportation. When DURASAR is used at normal suitable dosage levels, it will not significantly affect the concrete's heat of hydration.

PACKAGING, STORAGE AND HANDLING:

DURASAR is supplied in 260 Kg. drums or in bulk. It will freeze at -4.0° C. (25° F.). If frozen, warm to 22° C. (72° F.) mix well. Its working properties will not be affected if frozen. Storage of DURASAR at room temperature is recommended.

SAFETY AND HANDLING PRECAUTIONS:

DURASAR is a non-alkaline material. Direct contact may cause irritation of eyes. Prolonged contact may cause skin irritation. May be harmful if swallowed. Do not get in eyes. Avoid prolonged skin contact. Wash thoroughly after handling. Do not take internally.

WARRANTY STATEMENT:

The information given here is based on our best knowledge and we believe it to be true and accurate. We assume no responsibility for the use of these statements, recommendations or suggestions, nor do we intend them as a recommendation for any use which would infringe any patent or copyright.

MANUFACTURED BY:- HANDY CHEMICALS LIMITED
745 Ste. Rose Street
La Prairie, Quebec
CANADA J5R 1Z2

Telex: 05-24489 Tel.: (514) 659-9693